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METHODS OF INSECT CONTROL

PART II

Dwight Isely

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METHODS OF INSECT CONTROL

PART II

THIRD EDITION - REVISED

by

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by
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INTRODUCTION

Methods of insect control have been subject to frequent modifications during the past decade. In no part of the field is the succession of changes more impressive than in insecticidal control. This involves not only insecticides that are new but uses that are new for well known insecticides. Notwithstanding the new developments most changes are partial and the older methods continue under certain conditions. The utilization of both new and old methods gives greater inflexibility to control procedure and makes it more easily possible to adapt methods and materials used to suit special conditions. It marks a trend away from blanket rules which of necessity were depended on during the younger days of the science.

Notwithstanding the rapid change in materials available for insect control the basic reasons for applying the various methods used have not changed. Success in destroying insects depends upon applying measures during some weakness in the life history or seasonal history of the pests concerned. Success in development of insecticides themselves depends primarily upon the effect they may have on the insect at the time of this weakness and how they are adapted to the conditions which surround it.

The science of applied entomology is based on an understanding of why recommendations for insect control are made. The reasons given should be supported with evidence. Since there are more than several thousand injurious insects in the United States the number whose control can be adequately analyzed to supply this evidence is relatively small. For this reason no attempt has been made at exhaustiveness, either in examples or in citations to literature. The choice of pests which best illustrate a given method is sometimes open to question and preferences may vary with the year and the location. The illustrations presented here may be supplemented with others to suit the time and place.

Since we are concerned chiefly with the control of injurious insects, this discussion deals with those considerations which have a direct bearing on control. These naturally include the fundamental aspects of entomology upon which methods of control depend. Although a study of current practices is of first importance, nevertheless, a review of reasons why some measures have been superceded by others is in itself instructive as an indicator of lines of progress.

Most methods of insect control may be divided logically into two groups. The direct methods involving the use of insecticides are the subjects of most of the chapters of this volume, which is part two of this series. Those methods which depend upon evasion of insect injury by controlling the hosts or physical environment of the pest, or indirect control, were included in part one. The direct measures of mechanical control which are naturally associated with indirect measures were also considered with them. In practice these methods are not always easily separated. Success in applying insecticidal control is often dependant upon or enhanced by successful use of indirect measures.

CHAPTER I

THE PRINCIPLES OF INSECT CONTROL

The control of insect pests depends first upon a knowledge of factors causing or favoring the abundance of the species concerned. The removal or avoidance of these factors, when possible, is the first measure of control to be undertaken. This may be classified as prevention of insect injury, or indirect control. When this is not possible or not altogether effective, direct destruction of the insects by either mechanical means or by insecticides must be resorted to. Both indirect and direct control depend upon a more or less intimate knowledge of the insect's life history, seasonal history, habits, and response to environmental conditions. Such knowledge is necessary if measures are to be applied at the time when they are most effective, and if potential outbreaks are to be foreseen in time to prepare to combat them. For this reason the study of the control of any insect begins with a search for some weakness in its life cycle or activities. This information is gained through the often laborious studies of seasonal history and life history, which make up much of the literature of applied entomology.

Insect control should be understood as a relative term. Control of a pest implies reduction of injury by that pest to such an extent that the gain justifies the effort and expense of applying it. Control measures have been developed for some pests which if applied with reasonable care may prevent practically all damage, while those developed for other pests are of marked value only when applied with close attention to details. All control measures are subject to failure if carelessly applied.

In dealing with complex insect problems a single method of control may not satisfactorily suppress the pest. For such problems combinations of methods may be necessary. Sometimes a single method is the main dependence but support by others is required.

Methods of insect control may be classified as follows:

(1) Prevention of insect damage, or indirect control, usually involves making the environment for a given species as unfavorable to it as possible. This may be done by crop management, and by the use of various cultural methods known to be unfavorable to the pest in question. The results from this type of control, although often far-reaching, are seldom striking and do not appeal to the popular imagination. Preventive measures have a further handicap, when compared with emergency measures, of requiring planning from year to year, often when the pest to be controlled is causing no general concern. Consequently they tend to be neglected.

(2) Controlling insects by using their insect enemies is sometimes called biological control. In nature the insect enemies of insects may be of utmost importance, and in a few instances biological control as directed by man has been surprisingly effective. In general, however, its usefulness is limited. The application of biological control is strictly in the hands of entomologists and not of crop producers themselves.

(3) Direct control involves the destruction of insects by insecticidal or mechanical means. It is generally employed after an outbreak is in evidence. If successful, the results may be spectacular and hence it appeals to popular imagination. Insecticidal control in the mind of the layman is often regarded as the essence of applied entomology. On the whole, the possibilities of effectiveness of direct control may be less than those of indirect control. It is often utilized too late for best results. Because it is direct, however, and may be employed in

emergencies, the measures of direct control are the ones most frequently employed.

(4) When control measures are applied with eradication of an insect pest from a given area as their chief aim, it becomes a phase of governmental control. The exclusion of a species from a region in which it does not occur involves quarantines and their enforcement. Entomological employment which has enforcement of quarantines as its chief business may be called regulatory entomology, and responsibility for this is seldom placed on the farmer or the general agricultural worker.

The methods of controlling insects attacking field, truck, fruit, or forest crops are similar in many ways, but differ radically in how the emphasis is placed. The unit value of a crop or product often determines the methods used. On crops of low acre value expensive insecticidal and mechanical control measures cannot be considered. Very expensive measures are sometimes used in controlling shade tree pests that could not be justified for controlling the same insects on the same hosts in a forest. On annual field crops,rotation, the time of planting, soil management, and other types of indirect control may be used and are the chief features in the suppression of field crop insects. While such measures may be useful on annual crops, they cannot be readily applied to tree and bush fruits because of the relative permanence of these crops. With truck crops such measures as rotation might be readily applied, but the size of the field or plot is often so small that it may lose its value. On the other hand, the gross returns for each acre of fruit and truck crops may be large enough to justify more expensive means of control. For this reason control by means of insecticides is of dominating importance in the suppression of horticultural crop insects. Environmental factors can be utilized frequently, but they receive relatively less attention. In the control of field crop insects, crop management or indirect control is most important. Insect control in forests in some respects resembles control in field crops in that prevention rather than insecticidal control is stressed. Direct control is employed at times, however, by drastic cutting out or destroying blocks of infested timber.

The Analysis of an Insect Problem

In making an analysis of an insect problem information on certain aspects is essential. For this reason, a similar sequence of information occurs in most publications relating to insect control, although the attention given to the different features varies. The essential information includes a discussion of the insect's importance, a description at least of the stages commonly seen or of its injury, its scientific name, its geographic distribution, its hosts, an account of those features of its biology which is essential in timing control measures, factors which favor its abundance, and materials and methods used in its control. These considerations will be discussed more fully.

(1) Importance - It is essential to know the potential and usual destructiveness of a pest to determine the amount of attention one is justified in giving it, and the cost that may fairly be expended in controlling it.

(2) Recognition of Insects - An exact determination of the species concerned is usually necessary for an intelligent attack on an insect problem. Since there are so many destructive insects the student or the general agriculturist cannot be expected to recognize a large proportion of them. He should know, however, how to get an unfamiliar pest identified. The number readily recognized may be increased by experience. It is also an advantage if it is possible to place it in the group, or family, to which it belongs. The student may become familiar with characters by which insects may be distinguished most readily. Sometimes the most serviceable characters are the types of injury insects cause rather than the appearance of the insects themselves.

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(3) The Scientific Name is a means of identifying an insect in literature without which means one might go badly astray. Common names are often unreliable. It is not necessary as a display of pedantic learning as the layman is sometimes led to assume.

(4) Geographic Distribution - The distribution of an insect is not always a matter of importance so far as immediate control is concerned. It is of greatest interest to people, however, when an insect of foreign origin is not yet within the boundaries of their state, but may invade it at some time. Thus, the exact distribution of the pink boll worm, the European corn borer, and the Japanese beetle is a matter of public interest. Also with geographic distribution the history of the spread of a pest is often instructive.

One may also judge from the behavior and destructiveness of insects in one region what may be expected of them in others. In some regions within its range a pest may be of great importance while in others it is negligible. A comparison of conditions in the different regions may indicate the factors favoring abundance and then point out means of control. A knowledge of geographic distribution also sometimes assists in identifying an insect species in a given region or eliminating it from consideration.

(5) Hosts - An insect may feed upon one or many hosts. The distribution of these hosts determines the utmost limits of the insects' range, and the abundance may determine the possible insect population. Host management is one of the first resources of an entomologist controlling insect pests.

(6) Time and Manner of Application - Success in insect control depends more on applying control measures at the right time and in the right manner than upon any other factor. Exactness on these points may be even more important than exactness regarding materials used. The time of application of control measures is usually determined by the time of occurrence of some weakness in the life history or seasonal history of the species concerned. The manner of application depends upon a knowledge of life history, seasonal history, and habits of destructive insects. Other information is of secondary importance.

The terms life history and seasonal history are frequently confused. With some insects these periods may be coincident. They may be defined as follows:

The life history of an insect is the history of its development through all stages from egg to egg. The duration of a life history is variable. With the house fly it may cover only a few days; with the periodical cidada it may require 17 years.

Seasonal history, on the other hand, is the history of an insect through a season. It includes information regarding the number of generations, their time of occurrence, and hibernation.

The term habits is self-explanatory. The discussion of habits of an insect is often included with that of life history. A knowledge of such habits as food plants, method of feeding, manner of hibernation, and place of transformation is of most importance.

(7) Factors Favorable to Abundance - In a study of distribution and economic importance of a given species of insect, it will usually be found that its geographic range is much greater than the area in which it is destructive. Sometimes an insect may be very destructive locally although over the greater part of its range it is of negligible importance. The factors favorable to a species are generally found in the study of its life history, seasonal history, and habits.

5) The [illegible] ... [illegible] ... ought to be [illegible] ... [illegible] ... [illegible] ... [illegible] ...

[illegible] ... [illegible] ... be [illegible] ... of [illegible] ... of [illegible] ... or public [illegible] ... [illegible] of a [illegible]

[illegible] ... of [illegible] ... [illegible] on the [illegible] ... [illegible] ... in [illegible] ... [illegible]"

(4) [illegible] ... determines [illegible] ... the [illegible] ... of an [illegible]

[illegible] and [illegible] of [illegible] ... [illegible] ... materials [illegible] ... the [illegible] ... species [illegible] ...

The terms life history [illegible] ... these [illegible] ...

The life history [illegible] ... from [illegible] ... it may cover only a few [illegible] ...

Seasonal history, or [illegible] ... It includes [illegible] ... occurrence, and [illegible]

The term habitat [illegible] ... with [illegible] ... food or feeding, manner of [illegible] ...

(7) Factors [illegible] ... [illegible] of a given [illegible] ... is much greater than the [illegible] ... be very destructive [illegible] ... slight importance. [illegible] ... life history, [illegible]

(a) Host relations are probably the most important factor affecting the abundance or destructiveness of an insect. It is obvious that the range of an insect cannot exceed the range of its hosts. The abundance of its hosts, the sequence of hosts, whether of crops or weeds, and combinations of hosts, all modify the abundance or destructiveness of insects.

(b) The soil type frequently determines the range of a species. While this is of most importance in its relation to the distribution of subterranean insects, it also affects, at least indirectly, species that feed above the ground.

(c) Climatic factors, moisture and rainfall, and temperature, limit the distribution and abundance of insects. Winter temperatures, or the length of growing season, or a long season of favorable temperature, or relative humidity may furnish optimum conditions for reproduction and be responsible for unusual abundance of a species. These factors also affect the plant hosts and the optimum climatic range is frequently the same for the host and the pest.

(d) Insects have many natural enemies, insect and fungous. The abundance of these natural enemies is usually determined by climatic conditions and is seldom an independent factor.

(8) Materials - The materials used in insect control are insecticides and tools or machinery. These materials will be considered from the entomological viewpoint rather than from the chemical or mechanical.

Success in insect control depends upon attention to details more, perhaps, than success in many other fields of agriculture. This is especially true in dealing with the more difficult problems where carelessness in any particular may result in failure to secure a profitable reduction of injury.

CHAPTER II

MACHINERY FOR APPLYING INSECTICIDES

The manner of applying an insecticide may determine the degree of success which results from its use. The completeness of coverage with an insecticide, ease of application, cost of application, adhesion, all may be affected by the type of machinery and equipment used. Insecticides are usually applied to plants either in the form of dust or liquid. For this reason, before considering specific problems in control cursory attention will be given to methods of dusting and spraying. This discussion will also serve to define terms relating to insecticidal machinery, which are used in later chapters.

The usefulness of any manner of application of an insecticide must be determined by its effectiveness in controlling the insects against which it is directed. For this reason, so far as a type of machine or appliance affects the manner of application it must be considered as a part of the problem of control. It is not our purpose to discuss the mechanics or construction of dusting and spraying machinery. Such a study would be digression into the field of Agricultural Engineering.

Dusting versus Spraying

Dusting and spraying each have advantages as methods of applying insecticides.

Any insecticide in a liquid which is applied to a surface on which it dries invariably adheres much longer than the same insecticide applied as dust. As for instance, arsenate of lead applied as spray will adhere in considerable quantity to foliage for a period of weeks, while if applied as dust most of it disappears within a few days. A relative degree of permanence is of importance, particularly in applying stomach poisons which are expected to protect plants for a considerable period of time.

Spraying has an advantage over dusting if it is desired to apply an insecticide to a particular part of a plant. An insecticide carried by a liquid applied with a nozzle can be directed against the undersides of foliage of procumbent plants or against plant parts, like clusters of grapes which are more or less protected by foliage (4). Spray has more weight than dust and can be applied in spite of wind. With some of the smaller hand dusters the application of dust can be directed fairly well, but as a rule spraying results in more satisfactory coverage. On account of air movements, dusting must often be done at night when atmospheric conditions are more favorable.

It is possible to move dusting machinery loaded to capacity with an insecticide much more easily and rapidly than a sprayer loaded with a liquid spray mixture. As for instance, an orchard sprayer with a 200 gallon spray tank, when used for codling moth control, includes in 200 gallons of spray mixture probably not more than eight pounds of arsenate of lead. If applied as dust, the insecticide might be mixed with a diluent but seldom in amounts equivalent to more than 10 times its weight. For the same reason small hand dusters are also easier to carry than small sprayers.

An insecticidal dust is usually applied as a cloud of dust which settles over the plant parts to be protected. As has been pointed out the application is not usually directed at any particular part. For this reason dust applications usually take much less time than spray applications and are economical from the standpoint of labor.

From the point of view of the amount of materials used dusting is more costly than spraying. This is due in part to the same factors which make dusting more rapid. Also an insecticide applied as dust is seldom diluted to the same extent as when applied as spray. More dust probably falls on the ground than spray.

The advantages listed are general. Some insecticides can be used only in one form. As for instance, sodium fluosilicate should be applied on plants only in dry form. With other insecticides the particular results desired determine whether the material is applied as dust or liquid. The habits or susceptibilities of the insects concerned may also determine whether liquid or dust is used. These variations will be discussed more fully later.

Types of Dusting Machinery

The greatest development of dusting machinery has been in connection with dusting cotton for control of the cotton boll weevil. For this reason attention will be given first to dusters of this type (2). Cotton dusters may be classified as row dusters operated by a hand crank, row dusters operated by traction, and dusters operated by engine power.

The smallest of the row dusters, frequently called a "hand gun", is carried by the operator along the cotton row. With such a duster an operator can cover about an acre of cotton an hour. It is particularly adapted to dusting small patches, corners and ends of rows, and in weevil control to "spot dusting". A two-row hand operated duster being heavier is generally carried on a horse or mule and is called a "saddle gun".

Traction dusters for cotton are made to cover two to four rows and are known as wheelbarrow or cart dusters. None of these larger dusters can turn in the middle of a row and consequently are not adapted to "spot dusting". The traction dusters are also at a disadvantage in periods of rainy weather, particularly on the heavy bottom soils. On stumpy land traction dusters have a greater chance of breakage. Nevertheless, the cart dusters are the most satisfactory implements for dusting large acreages of cotton, particularly because they simplify the labor problem. This is due in part to the fact that cart dusters cover larger acreages than any of the other row dusters - 25 to 40 acres in a night. Also, since the operator rides above the cotton plants, he does not become soaked with dew, nor covered with the insecticide like the operator who walks between the rows. With all of these row dusters, however, the principle of application is the same and the degree of thoroughness is similar since all of them apply dust from a nozzle directly over the row. The dust is expelled continuously by a rotary fan.

Dusters which derive their power from an engine may discharge the insecticide through four or five outlets, like the larger cart dusters, or through a single outlet in a blast or cloud over the plants to be protected. These machines have the advantage of not being dependent upon traction to operate the blast fans. The machines with outlets for each row distribute dust more evenly, and can operate under less favorable atmospheric conditions.

Application of dust from an aeroplane is a type of plant dusting which covers a number of rows at a time. The great advantage of dusters of this type is the large acreage which may be covered by a single operator and consequently its simplifying effect upon the labor problem. Aeroplane dusting also has the advantage of being possible following rains when horse and tractor drawn machines could not be dragged through the fields. Since aeroplane dusting is done by contract, the responsibility and worry may be completely taken from the farmer. The expense is relatively high. This type of dusting is of value only on very large acreages, and where "over-all" applications are desired.

In addition to its use on cotton, aeroplane dusters have been used in a number of situations where any other manner of insecticidal application would have been impossible. The first aeroplane dusting was for the control of the Catalpa sphinx in catalpa groves in Ohio (3). Aeroplane dusting has since been used occasionally in the national forests for controlling leaf-eating caterpillars. They have also been used for dusting swamps with Paris green to destroy mosquito larvae, for distributing poison bait for grasshoppers, and for dusting sugar cane.

Power dusters are used in applying insecticides and fungicides in orchards as well as on cotton. Probably their principal use is in peach production, since on other fruits insecticides are generally applied as spray. Traction dusters are used extensively in production of truck crops. These traction dusters are usually row dusters and their operation is similar in principal to that of cotton dusters already discussed.

The bellows dusters are representative of a type of machine different from those already discussed, in that the dust is expelled intermittently with the movement of a lever. Such dusters are particularly useful in treating crops, like cucurbits, that are grown in hills. The small hand blow gun, which is sometimes useful in a home garden, applies dust in the same manner.

Insecticidal dusts need not necessarily be applied by machinery. In fact, most dusts applied in gardens are probably shaken out of a bag. A "bag and pole duster", that is a bag attached at either end of a pole as long as the width of a cotton row and carried on the back of a mule, was the first type of a cotton duster used in the control of the cotton worm. Such dusters are of value when even distribution of the insecticide is not necessary.

Types of Spraying Machinery

Spraying machinery varies in size and complexity from small atomizers to large power machines. More than half of all spraying is done in orchards and in this field gasoline-power sprayers of various sizes are used. The use of hand pump sprayers and traction sprayers is almost entirely limited to gardens and truck crops.

The chief requirements of a sprayer are that it shall deliver spray material of a given amount at a certain desired pressure and that the insecticidal mixture in the spray tank shall be continuously stirred to prevent the materials from separating or settling out.

Small portable sprayers, usually most suitable for a garden, are bucket sprayers. The so-called bucket pumps usually have no agitator with them. These little sprayers usually do not have any reserve pressure and must be pumped continuously if a constant delivery of spray is to be maintained. They are also light, breakable, and cannot bear high pressure. Nevertheless, on account of cheapness they are a useful type of sprayer for a small garden.

Knapsack sprayers are similar in character to bucket pumps in that they can produce low pressure only and are easily broken, but since they are connected with a small portable tank (usually 3 to 5 gallons) are more expensive. They usually are equipped with an agitator. Their advantage over a bucket sprayer is that they are made to be carried while in use.

Barrel pumps represent the best type of hand power sprayers. They are usually made heavy enough to supply a spray with a dependable, high pressure, but they require considerable labor to maintain this pressure. Sometimes they are used for spraying small orchards, and if too much is not expected of them they may be satisfactory for this purpose.

Traction sprayers derive their power like traction dusters, and deliver the spray in the same manner, from nozzles set over each row to be sprayed. Obviously, traction sprayers are usable only when the sprayer is kept in motion and consequently can be used only on row crops and not on trees where the sprayer must stop at intervals. The pressure maintained by a traction sprayer is relatively low when compared with a power sprayer.

Power sprayers all depend on the same essential principle, that is, the spray is delivered through a hose or pipe by a pump and the power is supplied by a gasoline engine. Usually they are hauled about the orchard, but large stationary outfits are used in some sections of the country. Stationary outfits introduce problems of agitation and pressure as well as high initial cost. In California the cost was estimated in 1926 at $37.50 an acre (6). The sprayers used in orchards (7) vary in size and power from those capable of delivering 2 or 3 gallons a minute to 20 gallons a minute and at a pressure ranging from less than 150 pounds to a square inch to 500 pounds a square inch. The sprayer tanks vary in size from a 100 to 400 gallon capacity.

Nozzles are sometimes arranged on spars at the rear of power sprayers or traction sprayers. If the machines are used for spraying truck crops like potatoes, a horizontal spar is used and each nozzle is set to deliver spray over a row of potatoes. The space between the nozzles obviously should be the width of the rows. Six or eight rows may be sprayed at one time. In spraying row crops, like grapes, vertical spars are used and the nozzles are spaced along them at distances dependent upon the height of the wires (4). Such spraying of grapes subjects the vines to a "fog" of spray which is very efficient in covering the outside foliage. It is not of value, however, in controlling pests that confine their attacks to the grape clusters after the vines are in full leaf. In its manner of coverage spraying of this sort resembles dusting in that it lacks direction but depends upon the mist covering to be so complete that no part of the plant can escape it.

Spray Nozzles

The differences in insect control secured in spraying fruit may depend not so much on the machine as on the amount of pressure the grower tries to get out of it, the type of nozzle and rod which he uses, and the size of the aperture of the nozzle. The most efficient type of spraying is done with a nozzle at the end of a rod which distributes spray as a fine mist (1). Rods may vary in length from about 3 feet for vineyard spraying, to 8 or 10 feet for orchard spraying. Its success depends on the operator's actually directing the spray on the fruit, cluster, or plant part which it is desired to cover. It is obviously the most expensive in the amount of time and labor required. Its weakness is that it depends upon the skill and dependability of the operator. For spraying tops of tall trees with a rod the operator must work from a tower on the sprayer.

For spraying the tops of tall trees, sometimes 80 feet high to control gypsy moth, solid stream spraying was developed (8). The nozzle used is the prototype of the "spray gun". Obviously, a very high pressure must be maintained for this type of spraying. Solid stream spraying is efficient in controlling caterpillars which are gross feeders on foliage.

The "spray gun" is a further modification of solid stream spraying. It is equipped with an adjustable nozzle so that it may throw either a solid stream or a mist or any combination of the two. Guns require more pressure than rods equipped with nozzles. Spraying with guns is more rapid than with rods and is the main dependence for spraying in many fruit regions. At first short guns were used, then longer guns, then long guns equipped at the end with a single adjustable angle nozzle.

A further compromise between rods and guns has been developed in a spraying device called a "broom". This is a short rod equipped with three or four and sometimes more nozzles. In effect it is much like a long gun and depends on covering a surface with a spray without directing the spray at each particular fruit or plant part. Work with a broom increases the speed of operation and requires more pressure than a rod.

The fineness of spray is largely dependent upon the size of the aperture in the nozzle and the pressure of the spray mixture delivered by the pump. For this reason specifications of the size of nozzle apertures and pressure are often included in spraying recommendations. Spraying with high pressure tends to produce spray injury more frequently than a relatively low pressure.

In order to insure as nearly a perfect spray mixture as possible all power sprayers are equipped with agitators. Where agitation is not good there is a tendency for insecticides to settle out or divide from the carrier. The result of such a separation would be that the insecticide is distributed unevenly in the spray, which in turn may be manifested in inefficiency in killing the insects concerned on some plants, and also injury to other plants where the insecticidal dosage was too high. To increase the completeness of distribution of the insecticide throughout the spray tank it is desirable to have a pump capable of delivering at least 50 per cent more liquid than is necessary in spraying to insure a heavy backflow in the tank. To facilitate agitation the bottoms of tanks of most power sprayers are either eliptical or semicircular.

Probably most spraying outfits are not equipped with enough agitators and those they do have run at too slow a speed. It has been suggested in California that the speed of agitators be standardized at approximately 200 revolutions per minute. The effect of agitation in a hose or pipe is reduced in proportion to its distance from the sprayer tank.

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CHAPTER III

CONTACT INSECTICIDES FOR THE DORMANT SEASON

Contact insecticides kill insects by coming in actual contact with them. In contrast stomach poisons kill only if eaten by an insect. As a rule contact insecticides are applied to control insects with sucking mouthparts in the orders Homoptera, Hemiptera, and Thysanoptera, and against mites of the Arachnid order Acarina. In addition to the usual use, they are occasionally recommended against insects which are ordinarily controlled by stomach poisons when those insects are gregarious or when quick action is desired. Contact insecticides are usually more expensive than stomach poisons and most of them are effective only at the time of application. These are the reasons why they are usually recommended only against insects which cannot be controlled by the latter.

The field of contact insecticides is similar to that of fumigants and occasionally overlaps it. Contact insecticides are usually sprayed or dusted on insects which occur on living plants. Fumigants are applied in buildings, on plants under tents or other covers, and in the soil. Their effectiveness depends upon a certain concentration of gas being introduced into the space around the insects to be controlled. Some insecticides like nicotine may be used either as a fumigant or as contact insecticides. At times it is difficult to draw a definite distinction between contact insecticides and fumigants, and the classification is a matter of convenience.

Because of the temporary effect of contact insecticides, the time of applying them is nearly always determined by the presence of the insect. They are almost never applied with the object of preventing damage before the pest to be controlled is in evidence. In the case of scale insects, white flies, or plant lice that feed on stems, this gives considerable latitude in timing applications. The margin may be narrow, however, for those aphids which twist foliage, like the rosy apple aphid. In the control of such insects spray applications must be made in the brief interval between the beginning of leaf growth and of the twisting of foliage. With insects which attack floral parts like the pear thrips the time during which applications may be made is also brief.

For the sake of convenience in discussion, contact insecticides will be divided somewhat arbitrarily into three groups: (a) contact insecticides most frequently used in dormant spraying; (b) contact insecticides used during the growing season; and (c) miscellaneous contact insecticides, like sulfur and sulfur compounds which do not belong exclusively to either category.

DORMANT SPRAYING

Oil emulsions are the insecticides most frequently used in dormant spraying. Most oils are themselves active insecticides, but the majority of them are injurious to plants if used alone. For this reason oils are usually applied in emulsions. Nearly all of the emulsions in general use are made from petroleum oils. Those which we shall consider are: Kerosene emulsion, miscible oils, lubricating oil emulsions, and white oil emulsions. Coal-tar distillate emulsions and other coal tar products are also used in dormant spraying for the control of insects which hibernate in the egg stage.

The constitution of an oil emulsion is described by Griffin (8) as follows: "In an emulsion of mineral oil with soap and water the mineral oil is divided into very small droplets which are suspended in the watery medium. The soap is added to keep these droplets from coalescing and finally separating out. Part of the soap is

broken down, the fatty acids being dissolved in the kerosene and the alkali remaining in the water; another part forms a film between the oil and the water preventing droplets from coalescing, thus stabilizing the emulsion."

Oils kill either by penetrating the tracheal system or by suffocation (4,6). A volatile oil like kerosene containing a large amount of unsaturated hydrocarbons passes through the tracheal system and into the entire body cavity, dissolving first the fatty tissue and finally even the entire cellular structure of the interior part of the body. Lubricating oils of the non-volatile, highly refined type penetrate the tracheal trunks for only a short distance and remain there indefinitely, apparently killing by suffocation.

Kerosene Emulsion

Kerosene emulsion is of interest as the type from which other emulsions used as insecticides were developed. It was first recommended as an insecticide, according to Lodemann (16), by Cook in Michigan in 1878. For many years it was the most important insecticide available against the sucking insects. At present kerosene emulsion has been almost entirely replaced by emulsions made from heavier oils. It is unstable, breaking down readily in hard water. For dormant spraying it must be used at concentrations that are relatively high if compared with emulsions of the more viscous oils. This high dosage is always near the limit of safety to plants, and as a result kerosene emulsion has been entirely superceded as a dormant insecticide. It is occasionally used during the growing season because the materials from which it is made are usually available and the emulsion is relatively easy to make. A standard formula for making a stock solution of kerosene emulsion is as follows:

Kerosene	2 gals.
Water (soft)	1 gal.
Soap	½ lb.

The soap should be dissolved in water heated to near the boiling point. After the soap solution is removed from the fire, the kerosene should be added and the mixture should be stirred or pumped until a creamy emulsion is formed.

Miscible Oils

Miscible oils are in reality stable emulsions which were developed as insecticides for controlling the San Jose Scale following the advent of this pest in the East. A miscible oil often contains a blend of oils; animal, vegetable, and mineral. The animal or vegetable oils are important in making the emulsifier. The greater part of the emulsion is composed of a petroleum oil which is more viscous than kerosene and effective against San Jose scale at a lower dosage. Miscible oils contain relatively little water and are not usually affected by freezing. Because of their stability they can be used with hard water and are not broken down in shipment. Miscible oils are practically all sold as proprietary insecticides and are seldom home made. The required dosage to kill San Jose scale varies depending upon the composition, although most commonly one part in 15 to 20 of water is recommended. While miscible oils are sold in competition with lubricating oil emulsions, their undisputed field is with the small isolated grower who cannot readily prepare other emulsions and who is not near enough a manufacturer of less stable oil emulsion to buy advantageously.

Lubricating Oil Emulsions

Lubricating oil emulsions are a simplification of miscible oils. An emulsion of this type was developed by Yothers (21) in Florida as an insecticide for citrus insects and mites. By using paraffin or red engine oil of high viscosity, he was ground them, the fatty matter being absorbed in the fissures [illegible] the [illegible] which [illegible] between the [illegible] and the water [illegible] from [illegible], thus [illegible] the emulsion.

This kind either by penetrating the [illegible] or by [illegible] like [illegible] of emulsified [illegible] through the [illegible] and [illegible] the fatty tissue and combine with the complex cellular structure of the inner part of the body. [illegible] cells of the [illegible], [illegible] the [illegible] and [illegible], [illegible].

[illegible]

[illegible] emulsion [illegible] were developed [illegible] as an introduction [illegible] against the sucking insects [illegible] emulsion has [illegible]. It is unstable, [illegible] must be used [illegible] with [illegible] of the [illegible]. This [illegible] is always near the [illegible] of [illegible], and as a [illegible] insecticide. It is [illegible] during the growing season [illegible] from which it is [illegible] to make. A standard formula [illegible] is as follows:

[illegible]
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The soap should be dissolved in [illegible] water and [illegible] the boiling point. [illegible] in [illegible] should be stirred or [illegible].

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Miscible oils, are [illegible] stable emulsions which were developed [illegible] for controlling the [illegible]. A miscible oil [illegible] the [illegible] of the [illegible]. [illegible] and [illegible], miscible oils [illegible]. Because of their stability they can be used with [illegible] water [illegible] are not [illegible] miscible oils [illegible] and the [illegible] into [illegible], although [illegible] of [illegible] in [illegible] who is not [illegible] to [illegible].

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able to greatly reduce the dosage of oil required to secure the same insecticidal efficiency. Because of the relative simplicity of manufacture, this emulsion was also much cheaper than the miscible oils which were sold at that time. The heavier oils are also apparently less injurious to plants during the dormant season since dosages can be used which are relatively lower than effective dosages of the lighter more penetrating oils. The possibilities of using lubricating oil emulsion on deciduous trees was not recognized until 1921 and 1922 when its effectiveness against San Jose scale was demonstrated (1). Since then this type of emulsion has become the most widely used dormant insecticide.

In the preparation of a stock emulsion by the so-called "boiled formula" the following materials are used:

Red engine oil	1 gal.
Water.	$\frac{1}{2}$ gal.
Potash fish-oil soap . . .	1 lb.

The oil, water, and soap are placed in a tank and heated until the contents begin boiling. Just before this a brown scum appears on the surface of the mixture and as it begins to boil this scum will gradually disappear. At this stage the mixture should pass through a pump twice under pressure of about 60 pounds to the square inch while still very hot. The first pumping may be made from the tank into a second container. The second pumping can then be made back into the original container or into barrels or other storage receptables. Stirring will not produce a proper emulsion nor should the mixture be allowed to cool before it is pumped (1).

Advantages and Disadvantages

The advantages of lubricating oil emulsion over its predecessors in the field of dormant spraying were greater dependability in scale control and a much lower cost. In comparison with most dormant insecticides which were in use at the time of its introduction, it was much more agreeable to handle, a factor which promotes thoroughness in spraying. No measurable injury to apple trees occurred when used in experiments over five and ten year periods (7).

The chief disadvantages in the use of lubricating oil emulsion made by the "boiled formula" are that oil is occasionally set free when the emulsion is mixed with hard water, and also that it freezes at a temperature of 15° F. which breaks down the emulsion. A weak Bordeaux mixture ($\frac{1}{2}$ lb. of bluestone, $\frac{1}{2}$ lb. of lime to 50 gals. of water) is the most satisfactory agent to make the emulsion mix with hard water (18). An excess of soap or a number of colloids also will serve as stabilizers. When a stabilizer is used it may be necessary to increase the dosage of oil by one-half of one per cent to maintain the same insecticidal efficiency (17). The presence of lime sulfur residue in the spray tank from the previous spraying season may also be responsible for breaking down the emulsion. To prevent this lime sulfur residue should be cleaned out with a strong solution of caustic soda or lye. The manufacture of lubricating oil emulsion is too complicated to be handled conveniently by most fruit growers and since it does not bear shipment well, it is generally made by insecticide dealers in plants located in the fruit belts.

Cold-Stirred Emulsions

A method more suitable for making oil emulsions in amounts needed for a small orchard was developed and has been designated as the "cold-stirred formula" (23). As an emulsifying agent an excess of soap or any one of a number of colloidal

materials may be used. "Cold-stirred" emulsions are not only easier to make than the boiled emulsion, but can usually be used in combination with hard water. Those in common use, however, cannot be stored but should be made just before using.

The formula for stock solution recommended by the "Committee on Oil Emulsions" (25) of the American Association of Economic Entomologists is as follows:

Red engine oil	2 gals.
Water.	1 gal.
Calcium caseinate.	4 ozs.

Other emulsifying agents including kaolin, glue, or skimmed milk powder may be substituted for the calcium caseinate (22). In each case the emulsifier is added to the water first and the oil is added slowly after the emulsifier is dissolved. The mixture must be run through a spray pump three times before it is fully emulsified.

Further stability of cold-stirred emulsions was secured by limiting the amount of water to that contained in the soap. A formula of this type is as follows:

Lubricating oil	9 gals.
Resin fishoil soap.	1 gal.

In making this emulsion a small quantity of oil, not to exceed one-third of the soap, should be stirred into the soap and no more added until this is completely mixed. The resulting emulsion is a stiff jelly-like mixture, and when diluted for use water should be added to it gradually instead of putting the stock solution into the tank as is done with other emulsions.

Effect of Emulsifying Agents

The insecticidal effectiveness of an oil spray depends in large part upon the amount of oil deposited. For many years it was assumed that the oil deposit depended upon the proportion of oil in the spray mixture. While this is a factor the amount of the deposit is also affected by the amount and type of the emulsifier used.

Spray applications with very stable emulsions tend to run off of the surfaces sprayed more quickly than the less stable emulsions. For this reason when an excess of soap or Bordeaux mixture is used with an oil emulsion as a stabilizer it has been found necessary to compensate for this excess stability by increasing the dosage of emulsion used. Reducing the amount of the emulsifying agent to the minimum resulted in what is called a quick breaking emulsion. In this type of emulsion, the film of emulsifier and water around the oil droplets breaks almost as soon as the spray strikes the surface. The water runs off leaving the oil film. This quick breaking characteristic increases the oil deposit.

The type of an emulsifier used may be as important as the quantity of oil in an emulsion. For instance, recent experiments in New York (2) have shown that in an emulsion in which blood albumen is used as the emulsifying agent the deposit in an emulsion containing two per cent of oil on bark of trees will be as great as that from an emulsion in which goulac is used and which contains 4 per cent of oil.

Tank Mixing of Oil and Water

When miscible oils first came into use one object striven for was stability of the emulsion. This is an important qualification of any emulsion which must stand for days or months, or which is shipped considerable distances before using. When

different emulsifying agents are used the effect of these emulsifying agents on runoff varies. The effect of a given agent may also vary according to the hardness of the water. For these reasons absolute consistency of performance by an emulsion used under varying conditions cannot be expected.

To meet this situation tank mixing of an oil spray was developed in California (19). This involves adding oil to the tank of water just before beginning spraying and then sifting in a spreader. A blood albumen spreader used at the rate of 4 ounces to 100 gallons of spray mixture was first recommended. This spreader consists of one part of blood albumen and three parts of fullers earth. Success depends in a large part upon the effectiveness of the agitation. This forms a mechanical mixture not an emulsion. A mechanical mixture of oil and water is a logical development following quick-breaking emulsions. Tank mixing in variously modified forms is now used in a number of fruit producing regions.

White Oil Emulsions

Miscible oils and the lubricating oil emulsions are essentially dormant spraying materials. The unsaturated hydrocarbons which they contain may constitute a desirable part of their insecticidal properties, but are also the most important factor in foliage injury. Lubricating oil emulsions were developed for spraying citrus trees in foliage in Florida, but were used at a relatively safe dosage of only one per cent. In California, where more resistant scales occur, a higher concentration of oil was necessary (20). To increase the dosage without increasing the probability of injury, oils from which the more injurious constituents were removed were used in making emulsions. These are the so-called white oils, which are highly refined by treating the oils with sulfuric acid or with liquid sulfur dioxide, which dissolves the unsaturated hydrocarbons and with them forms a dark sludge. The sludge collects in the lower part of the treating tanks where it is drawn off. The purified oil is then neutralized by washing in an alkaline solution, and then is washed in water. The purity of spray oils is determined by the sulfonation test and the degree of purity is expressed in terms of the percentage of oil that remains unchanged after treatment. The chance of foliage injury decreases with the degree of refinement of the oil, while the cost increases.

White oil emulsions are used on broad-leaved evergreens, in summer spraying of deciduous trees, or as substitutes for unsulfonated oils wherever the latter cannot be used with safety.

Specifications for Oils

The insecticidal efficiency of oils used in spraying is generally governed by the heaviness of the oil, and the quantity deposited on the tree or insect. Whether or not oil is light, medium, or heavy is usually determined by its viscosity (4, 19). Viscosity has been described as the rate of flow through a definite orifice and at a standard temperature in comparison with that of water as the standard. Usually it is expressed in terms of the number of seconds required for 60 cc, at a temperature of 100° F., to flow through a small orifice in an instrument known as the Saybolt Universal Viscosimeter. Smith (21) considers the distillation ranges as a more reliable indicator of the heaviness of an oil. This is determined by the minimum and maximum temperature between which the distillation of an oil takes place, and the percentage of oil distilling at points within the range.

The choice of oils used in dormant spraying has been determined largely by its effect on the San Jose scale. Large droplets in an oil have been found to increase its toxicity (9). Nevertheless, entomologists in different parts of the United States are not in agreement regarding the most satisfactory viscosity. For the con-

trol of the San Jose scale a viscosity of 200 seconds Saybolt is recommended in Arkansas; 125 seconds in the southeastern states; and 90 to 100 seconds in the Pacific Northwest. The amounts of oil in the dilute spray mixture recommended for control of San Jose scale in these various regions is 2 per cent, 3 per cent, and 4 per cent respectively. The volatility should be low, and not more than 1.75 per cent (18). The unsaturated and aromatic hydrocarbons are the components of spray oil which are most likely to injure trees and are usually designated in spray oil as impurities. These impurities are largely removed from the white neutral oils, but usually not from oils used in spraying dormant deciduous trees.

To improve the stability of an emulsion both manufacturers and growers have a tendency to increase the amount of the emulsifier or to add spreaders either to the stock emulsion or the dilute mixture. This has been found to reduce the effectiveness of the emulsion (3, 5, 17), as has been stated in the discussion of emulsifying agents.

Tar Oil Emulsions and Related Materials

Coal tar distillate emulsions were introduced into the United States from England during the last decade, as insecticides for the dormant season particularly for the control of aphids (10, 13). Coal tar is a byproduct of the manufacture of coal gas and of coke. The tar distillate used most commonly is creosote oil which includes fractions distilling between 55° C. and 200° C. The product is a black tarry liquid with an odor like creosote. The tar acid content should be less than 10 per cent. Tar distillate emulsions have the disadvantage of being expensive and of being caustic and hence disagreeable to use. The various emulsions which appeared on the market are not standardized as definitely as are the petroleum oil emulsions.

Crude cresylic acid, a coal-tar product, had been suggested as early as 1929 (11) to be used in dormant spraying in combination with oil emulsion for control of apple aphids. Soon after the usefulness of coal tar emulsions become established definite compounds which are byproducts of the coal tar industry were developed for use in dormant spraying. Among the better known of these materials is dinitro-o-cyclohexylphenol, (frequently known in entomological literature as DNOCHP or as DN) (10, 15). Other dinitro compounds have been used in the same field. When these materials are used in dormant spraying they are dissolved in a dormant oil before emulsification. They appear to have replaced the tar oil emulsions to a great extent.

Insecticidal Uses

Oil emulsions are considered chiefly as insecticides to be used in dormant spraying. The dosages of lubricating oil emulsion recommended for the control of San Jose scale are generally effective against other armored scales with similar life histories. They may be used also in the control of other scale insects, but at much higher dosages. Oil emulsions are also recommended as dormant ovicides for certain tortricid moths, like the fruit tree leaf roller, which passes winter in the egg stage; as a dormant spray for the pear psylla; and for white flies on citrus.

Miscible oils dispute the field as a dormant spray material for deciduous fruit trees with the lubricating oil emulsions. They are used more extensively, by small isolated growers and for spraying home orchards, since the emulsion is more stable and bears shipment better. The producers of miscible oils frequently claim that their product is more nearly standard than that of the lubricating oil emulsions.

The white oil emulsions are used as scale killers chiefly when it is necessary to spray trees in foliage. White oils are also used as supplementary spray materials to be applied in summer with other insecticides to add to their sticking and spreading qualities or to add directly to their efficiency as a contact insecticide.

Kerosene emulsion is now used relatively little. It still has a place in summer as an aphidicide, provided a better insecticide is not available, and where a volatile oil is desired. Perhaps its greatest usefulness is in the home garden. Its limitations as a dormant insecticide are indicated by the fact that an emulsion containing 20 per cent kerosene was necessary.

Tar oil emulsions and compounds derived from them are useful as dormant insecticides chiefly as ovicides. When it is desirable to have a combination spray to kill both armored scales and aphid eggs, it has been recommended that one of these materials and an oil emulsion be combined.

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[illegible] oil emulsion may be used as a [illegible] especially when it is necessary [illegible] in foliage [illegible]

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CHAPTER IV

DORMANT SPRAYING

Insects which may be killed by a contact insecticide at any time during a long period represent one of the simplest problems in timing control measures. Some of the armored scale insects which are included in the subfamily Diaspinae are vulnerable throughout the dormant season and can be used to illustrate this type of problem. In studies of these insects information regarding the duration of the various stages and the time of their occurrence is not of first importance in the problem of control. Special attention is given to the insecticide used. In the choice of an insecticide there is more latitude than there would be if the material was applied on trees in foliage.

THE SAN JOSE SCALE

The San Jose scale*, a major pest on deciduous fruit trees, will be used as an example of this type of problem. This insect is one of the armored scales. Recognition of the occurrence of this scale in California in the 1870's and of the threat which it offered to the deciduous fruit industry of the country was an entomological event of first importance. Its control has been the object of most investigations relating to dormant spraying, and much of our knowledge of contact insecticides is based on these investigations. About 50 years elapsed before a satisfactory insecticide was found.

The armored scales are examples of extreme degeneracy among insects. The nymphs of the first instar are mite-like and active until they settle down to feed. After they insert their slender threadlike beaks in the epidermis of their hosts, the females never move to another location. With the first molt they shed all their appendages except their mouth parts, and become mere sucking bags. A waxy covering or "scale" is secreted over their bodies, which serves to protect them from many sources of danger and from which the name armored scales is derived. When mature the females reproduce by oviposition or by giving birth to active young, depending upon the species. They remain with their mouthparts inserted in the same places where they have spent their entire immature lives. The male scales also remain fixed until they reach the adult stage. After completing their growth, however, they pupate and later transform to the adult stage. At this time they regain active life and again have all the necessary appendages, a pair of mesothorasic wings, legs, eyes, and genitalia. They have no mouthparts and need none since their function during the final instar is reproductive only. The adult males live but a short time and are seldom seen. For dispersion the species depends entirely upon the activity of the newly hatched nymphs, which may move a few feet by themselves or may be carried to nearby trees by larger insects or on the feet of birds.

Economic Importance and Hosts

The San Jose scale is potentially capable of ruining the deciduous fruit industry in the United States. By sucking sap through the bark of its hosts, it may reduce the rate of growth or vitality of the trees and when infestations are severe may kill them outright. Wholesale killing of large acreages of trees is not common since fairly effective control measures have been developed. Nevertheless, as recently as 1921 it was estimated that 500 acres of apple trees were killed outright in northwestern Arkansas and the vitality of trees on many hundreds of other acres was seriously reduced (1). Even if the scale is controlled, trees that have been seriously injured may require several years to recover and weakened trees may be

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*Aspidiotus perniciosus Comstock; family Coccidae.

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subject to additional troubles. Weakened peach trees in particular are more subject to injury by bark beetles than vigorous trees. A direct loss is caused by scales on fruit, giving it a spotted appearance and often rendering it unmarketable (4).

The San Jose scale is generally known as a serious pest of apples and peaches. Its importance on these hosts is emphasized by the greater commercial value of these crops. Probably it will injure or kill peach trees more quickly than any of its other hosts although injury to domestica plums is often as severe. As a rule apple trees will survive heavy infestations longer than peach trees. There is marked variation in susceptibility to scale injury among varieties of apples. In blocks of trees in which Grimes and Summer Champion are killed, Winesap and Jonathan may survive for years. Heavily fertilized, rapidly growing apple trees seem to be more susceptible to heavy infestation than slowly growing trees. Among pears, varieties of European origin are susceptible to infestation while the Chinese varieties are not. The only commercial deciduous fruit tree which is not seriously injured is the sour cherry which is seldom infested. Among bush fruits the currant is more heavily infested. Severe injury also occurs on certain pomaceous ornamentals like the Japanese quince, the cotoneaster, the June berry (Amelanchier sp.), and the mountain ash (Sorbus sp.). A list of its hosts upon which it is commonly found includes 71 species (2). The number of hosts upon which it has been occasionally is much larger. On many of these hosts, however, its occurence is of no significance except as a source of distribution. While most of the seriously damaged hosts are included in the family Rosaceae, heavy infestations occur on plants as distantly related to this family as the black walnut and the osage orange.

History

The San Jose scale is a native of China (6). It was accidentally imported to the San Jose valley of California, probably on ornamental peaches. By 1873 it attracted attention although the species was not described until 1880 (3). Its rapid spread over the United States attracted a great deal of notoriety. In spite of attempts of entomologists to designate it as the pernicious scale or the Chinese scale, the public attached to it the name of the valley in which its economic importance was first recognized. By the late eighties it was recorded from all the states of the Pacific Coast, and in 1893 was found in Virginia (7). Within a few years it was learned that it had become widely scattered on nursery stock over the states east of the Rocky Mountains. The spread of the San Jose scale is of importance in entomological history because it stimulated investigations in contact insecticides which now have a wide usefulness in the control of many insects. Furthermore the prevention of its spread on nursery stock was the object of the first organization in many states of inspection services and the establishment of quarantines to prevent the spread of insect pests.

Description

The scale insects are minute, yellowish, flattened, soft-bodied insects, and are themselves seldom seen. What is usually recognized is the waxy, scalelike secretion over their bodies, which is itself small and flattened. The scale of a fullgrown female when viewed from above is circular in outline and about a millimeter in diameter. From the lateral aspect, it appears somewhat curved with a raised nipple in the center. The scale of the male is smaller and somewhat elongated. In color scales are gray. The adult male is a minute two-winged fly.

Isolated scales may not be readily observed, but where there is a heavy infestation they may completely cover the surface of the twigs and branches they infest and give them a grayish appearance. When incrusted surfaces are rubbed and the bodies of the scales are crushed, the surface becomes oily. If scales are abundant,

they also infest the foliage and fruit. Infestation on green fruit is particularly noticeable because of the red spots that surround each scale, and similar red spots may also mark the location of scales on bark.

Seasonal History and Life History

In the greater part of the United States the San Jose scale hibernates as a partly grown nymph. When sap begins to flow, the scales begin to feed and grow. The minute winged males appear, mate with the partly grown females, and die, before the latter are fully grown. The San Jose scale does not deposit eggs but gives birth to active young which crawl about for a few hours before they settle and begin feeding. In Arkansas this may occur in the latter part of April or early May. In about 33 to 40 days after birth the new generation begins reproducing, and the average number of young produced by a single female is said to be about 400 (6). The number of generations depends upon the length of the season. Thus, in the southern part of its range the increase during a season may be very high. In the Gulf States it is probable that reproduction continues during favorable weather throughout the winter (8).

Natural Enemies

The San Jose scale has a large number of natural enemies, the most important of which are certain lady beetles in the family Coccinellidae, and hymenopterous parasites in the family Aphelinidae of the superfamily Chalcidoidea. It is also attacked by entomophagous fungi. These natural enemies are doubtless often of importance in checking multiplication but seldom can be depended upon to such an extent that the usual control measures can be omitted.

Control

The weakness in the seasonal history of the San Jose scale is during the dormant period. During this season of the year the trees are without foliage and the scale cannot move, and for this reason it can be hit more readily with a contact spray than at other times of the year. Furthermore, the fact that the trees to be sprayed are in a dormant condition makes possible the use of a wider range of spray materials, some of which might be injurious during the growing season. The time of application is not narrowly limited. The problem is essentially one of the insecticide to be used.

In the earlier efforts for control of the San Jose scale, spraying with soap washes, kerosene emulsion, crude oil and distillate oil emulsions, and fumigation with cyanide were tried, with varying success and in some instances resulting in injury to trees. Later lime-sulfur solution and miscible oils came into general use. At times these insecticides seemed to be fairly satisfactory. Lime-sulfur was effective, however, only when temperatures were relatively high, which usually occurred during the latter part of the dormant season, and also the scale appeared to develop a degree of resistance to this insecticide. In 1922 the usefulness of lubricating oil emulsion in control of the San Jose scale was demonstrated. While modifications of the original formula have been made to suit local conditions this type of insecticide is chiefly depended upon for scale control.

Oil emulsion may be applied at any time during the dormant season when it is warm enough to apply a liquid spray. As a rule a single application is sufficient to control the scale. An unusual degree of thoroughness in covering all the infested twigs and branches is required since the scale's capacity for reproduction is such that it can quickly overcome a setback. The dosage and various types of emulsions that may be used have been discussed under specifications for oils in the previous lecture.

THE OYSTER-SHELL SCALE

Many of the diaspine scales resemble the San Jose scale in most of the essentials of development, except that the females deposit eggs instead of giving birth to living young. Many of these scales pass winter in the egg stage and as a result are not susceptible to control at that time by an insecticide which kills by suffocation. The oyster-shell scale* is a representative of the Diaspinae with this type of life history.

The oyster-shell is one of the more important scale insects attacking the apple and ornamental trees and shrubs in the northern part of the United States. Apparently it occurs in two biological races, one of which is a pest of the apple and dogwood and the other a pest of lilac, ash, poplar, and other shade trees (9). It has been recorded from 128 hosts (12). It is not generally regarded as destructive as the San Jose scale although limbs on trees that are incrusted with scales may be killed and it has been known to kill forest stands of ash (11). The distribution of the species is worldwide.

Life History and Seasonal History

The oyster-shell scale is elongate and is wider near the posterior end which is rounded. The color is brownish gray. When fully grown it may be one-eighth of an inch long.

Winter is passed in the egg stage under the scale of the female insect. The eggs hatch in spring after their hosts are in leaf. If hatching begins during a period of warm weather, all eggs may hatch in a few days. On the other hand, during cool springs the period may continue over two weeks. The nymphs scatter and in a few hours settle on the bark of the host trees, where they remain the rest of their lives. When fully grown the females deposit eggs which remain under their scales and then the females die. The number of eggs deposited by a single individual may exceed 100, but the average found by Griswold was approximately 62. In the more southern part of their range two generations a year may occur (10).

Control

The hibernating stage of the oyster-shell scale, like that of the San Jose scale, is fixed on the bark of the tree where it can be hit with a contact spray. Since it is in the egg stage, however, it cannot be killed readily by an insecticide like oil emulsions whose effectiveness depends on clogging or penetrating the spiracles. A very high dosage of oil emulsion will kill the eggs, but such dosages are also likely to injure the hosts. For this reason the application of contact insecticides during the growing season when the eggs are hatching was at one time among the measures recommended. Spraying at this time was necessary since no insecticide which is safe on trees in foliage is effective in killing them after they are protected by their waxy covering. This was not altogether satisfactory because hitting all the "crawlers" when trees are in foliage is impossible and if the hatching period was extended over a week, more than one application was necessary for best results.

Contact insecticides which are effective in destroying eggs of aphids during the dormant season have also been found to be effective in the control of the oyster-shell scale. Experiments by Hartzell and Moore showed that either a coaltar oil emulsion containing 4.5 per cent of tar oil or a 4 per cent emulsion of lubricating oil in which 4 per cent of DN is dissolved would kill over 98 per cent of the oyster-shell scales on apple trees (10).

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*Lepidosaphes ulmi (L.)

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SUMMARY

The San Jose scale passes winter as a partly grown nymph which is accessible to control throughout the dormant season. It may be killed by an oil which either penetrates the spiracles and dissolves the body tissues, or clogs the spiracles producing suffocation.

The oyster shell scale is also readily hit by an insecticide but it passes winter in the egg stage and consequently is not accessible to control at this time through its respiratory system. The eggs may be destroyed, however, by insecticides derived from coal tar which are applied with oil emulsions.

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CHAPTER V

CONTACT INSECTICIDES FOR THE GROWING SEASON

The requirements of an insecticide for spraying plants during the growing season are more exacting in many respects than for dormant spraying. Fruit, foliage, or growing terminals are more susceptible to spray injury than dormant trees, and this susceptibility limits the choice of materials used. An insecticide which leaves a residue on foliage for a long time may interfere with photosynthesis and other functions and for this reason the viscous oils must be used with caution. Insecticides which penetrate the tissues may also cause injury. On the other hand there may be an advantage in an insecticide whose action is prompt but which does not remain long on the trees. The presence of foliage may also interfere with hitting the insects to be controlled.

Nicotine

Nicotine is at present the most generally used contact insecticide for the control of insects, particularly those in the order Homoptera, during the growing season. For this purpose nicotine holds relatively the same position that oil emulsions hold among insecticides for the dormant season. It has a number of competitors which include two other insecticides also derived from plants, rotenone and pyrethrum, certain aliphatic thiocyanates, soaps, and sometimes emulsions of the lighter oils.

Nicotine is usually sold in the form of nicotine sulphate containing 40 per cent nicotine. In this form it is an effective insecticide against most aphids when used at the rate of one part in 800 of spray mixture. Probably for this reason most of the competing insecticides when sold in liquid are also standardized so that a dosage of one to 800 will give a fair kill of aphids. Often the results are not quite as good as those secured from using nicotine, probably because, as pointed out by Garman (4), nicotine has considerable reserve at this dosage.

Tobacco dust and tobacco decoctions were among the contact insecticides recommended in the early years of applied entomology. The former was generally ineffective while the latter was so variable that it could not be depended upon. They have been replaced now by insecticides in which the nicotine content is definitely known. As already stated, usually nicotine is placed on the market in the form of nicotine sulfate containing 40 per cent nicotine. Among the advantages of nicotine are its great margin of safety on plants, and the readiness with which it can be combined in nearly all spray mixtures. Its disadvantages are its cost and the fact that it is disagreeable to use.

Nicotine is applied in liquid or in dust, and also as a fumigant. It kills by fuming action when applied in dust and usually when applied in a spray. Nicotine spray solutions do not penetrate the integuments of insects, nor do they necessarily pass into the trachea, according to McIndoo (7). He states that "the fumes from nicotine used as a fumigant, the vapors from nicotine spray solutions ... or from powdered tobacco pass into the trachea and are widely distributed to all the tissues. Regardless of how it is applied, wherever nicotine kills insects ... it kills by paralysis." Nicotine solutions themselves may also penetrate the trachea, however, and volatilize within them (10). When this occurs nicotine is probably effective at lower concentrations than when it depends upon fuming action alone.

The killing efficiency of a spray or dust containing nicotine is directly proportional to the volatility of the nicotine (3, 9). Free nicotine is quite volatile, but nicotine sulfate, the form in which the insecticide is usually applied, is

relatively non-volatile. "The toxicity of nicotine solutions varies in proportion to their conversion from the salt form to the free alkaloid", according to DeOng (3). He has shown that the degree of toxicity of nicotine follows closely the rapidity of volatilization, not only when applied as a fumigant or a spray, but also when applied as a dust.

Liquid nicotine sulfate is not effective until combined with an alkaline substance which frees the nicotine. DeOng also states that nicotine sulfate applied with soft water is likely to show a poor kill, while the same dosage of nicotine is effective when applied with hard water. Soap or calcium caseinate which may be added to the spray mixture to increase the spreading quality may also aid in breaking down the nicotine sulfate.

The degree of effectiveness of nicotine solutions also depends upon their being used with a proper wetting agent. The effectiveness of four solutions used by Wilcoxon and Hartzell was shown to be in order of their spreading coefficients (10).

The application of nicotine sulfate in a dust carrier is of more recent origin than its application in liquid (2). Colloidal clays, such as kaolin impregnated with nicotine sulfate, were first used as carriers, but it was found later that the carbonates and hydrates of lime were better (9). The materials used as carriers have been divided into three classifications: (2) "Adsorbent" carriers, like kaolin and talc, which retard volatilization of nicotine, (b) inert carriers, such as sulfur and gypsum, and (c) "active" carriers which change nicotine into a volatile form, like the carbonates and hydrates of calcium and magnesium.

Temperature is also a factor in the rapidity of volatilization of nicotine. Volatilization of nicotine has been found to be slightly more than doubled by an increase of temperature from 70° to 100° F. at a relative humidity of 70 per cent.

Nicotine dusts are sold ready mixed by various manufacturers. Ready mixed material has the disadvantage that upon exposure to air it rapidly loses its toxicity. Nicotine sulfate is easily mixed with hydrated lime before using, and this is to be recommended whenever possible. Possibly the best method for mixing nicotine dust is in a rotating barrel. The barrel with a pipe or rod passed through its ends, should be mounted on axles or any suitable support so that it can be turned rapidly. A 6 to 8-inch door should be cut in one side. To facilitate mixing the nicotine and lime, a half pound of small stones about an inch in diameter should be added for each pound of lime. After the lime, nicotine sulfate, and the stones are placed in the barrel, it should be rotated slowly for about five minutes. When the mixture is removed, the stones should be sifted out. To make a two per cent dust, five pounds of nicotine sulfate containing 40 per cent nicotine should be used in 95 pounds of hydrated lime. Dust should be used immediately after mixing, since hydrated lime liberates the nicotine and its insecticidal value is reduced by standing. The efficiency of nicotine dust is increased by dragging a trailer of canvas after the distributing machine.

Spraying with nicotine has the advantage over dusting when applied against aphids on trees, for this method of application is much more economical of materials. It is necessary, however, to hit about 95 per cent of the aphids if spraying is to be effective, since their rate of reproduction is so great that they can quickly recover a setback in numbers. With dust applications it is not necessary to actually hit so large a percentage of the insects, but the application must be heavy enough to insure a lethal density of gas in the surrounding air. For this reason nicotine in dust can be applied with advantage to truck crops, particularly those which lie close to the ground where the lethal density of gas can be more easily concentrated.

To insure the maximum concentration of gas, nicotine is sometimes applied in the field under a canvas and muslin trailer in the form of "nicotine vapor" (1). The distributor is drawn by a light truck or tractor. The nicotine is dripped regularly into the exhaust line of the engine where it is volatilized by the heat of the exhaust and carried through the discharge pipes under the trailer. This is in effect field fumigation.

While rapid volitilization of nicotine is generally sought, nevertheless for use with some insect problems a more stable nicotine compound which would be effective over a period of days would be desirable. At present the most satisfactory stable combinations for this purpose have been nicotine "fixed" in bentonite. Fixed nicotines are used most commonly as stomach poisons and will not be discussed here.

Rotenone

Rotenone is the most important insecticide obtained from the ground roots of certain leguminous plants which grow in tropical Asia and tropical America. The first source was plants of the genus Derris (Deguelia) which is of East Indian origin. The insecticide was first sold as derris extract. The active principle, rotenone, was isolated later. More recently it was found that rotenone could be secured profitably from cube from Peru, timbo from Brazil, and barbasco from Venezuela. All of these plants are included in the genus Lonchocarpus. They were used as fish poisons by Indians. Rotenone also occurs in other tropical American plants in the same family (13, 14).

Rotenone bearing insecticides are sold as derris, cube, timbo, or by various trade names. The rotenone content should always be stated. However, insecticides containing the same amount of rotenone but from different plant sources have similar but not necessarily the same insecticidal effectiveness. This is because other less important insecticidal compounds called rotenoids (14) also occur in these plants. The rotenoids which occur in the different species are not necessarily the same, nor are the proportions the same.

Rotenone is a relatively new insecticide. Derris extracts were manufactured in Great Britain as early as 1911, according to Roark (14). Derris root was not brought to the United States in commercial quantity until 1931. Importation of cube began about the same time, and of timbo in 1935. In 1940 over six and a half million pounds of rotenone-bearing roots were imported into the United States (14).

When the toxicity of freshly extracted rotenone was first determined by laboratory entomologists and chemists, the insecticide was seized upon by various enthusiasts who made extravagant claims for its usefulness. Field experiments did not justify these claims. One reason for the failure of rotenone to measure up to expectations is that it breaks down rapidly in the presence of light or oxygen, and also in certain materials which are used as solvents or carriers (11). Its maximum toxicity at best is only for a relatively short time and such being the case cannot give the continuous protection to plants which is required by stomach poisons. Temporary effectiveness, however, is characteristic of many contact poisons and in this use it is not necessarily a handicap. Rotenone is also quite variable in its effect on insects with similar habits, and generalizations regarding its effectiveness in controlling an insect do not necessarily apply to a similar species.

Rotenone insecticides are applied either by spraying or by dusting. When intended for spraying the insecticide may be obtained either in the form of a liquid extract or a powder which may be added to the spray mixture. A wetting agent in the spray mixture is usually recommended.

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Rotenone kills like nicotine by attacking the nervous system of insects resulting in paralysis. It kills by contact and not in any way by fuming action and does not necessarily enter the tracheal system. It is slower in action than nicotine and pyrethrum. If applied in liquid its efficiency is favored by a high relative humidity which retards evaporation. Activity is not favored by high temperature to the same extent as with nicotine, and consequently its action is less likely to be interfered with when temperatures are low. When applied in dust form derris or cube powder may be diluted with talc, sulfur, walnut shell flour, or other non-alkaline dusts. The addition of a conditioning agent like sodium laurel sulfate to the dust mixture adds to the efficiency of the insecticide.

At first rotenone was most frequently recommended for the control of insects affecting animals. Its temporary toxicity and its presumed relative harmlessness to higher animals made it particularly desirable for this purpose. More recently its usefulness as an insecticide on crops has been demonstrated.

The field of rotenone as a contact insecticide on crop plants is first as a substitute for nicotine in its control of various sucking insects including aphids. For some species, particularly those which must be controlled when temperatures are relatively low, it may be preferred to nicotine. If a dosage necessary to produce a similar degree of control on aphids as that of a 40 per cent nicotine solution be taken as a standard, rotenone is relatively more effective than nicotine against certain bugs like the harlequin cabbage bug, and also against mites of the family Tetranychidae like the common red spider.

Pyrethrum

Pyrethrum is a contact insecticide made from ground flowers of three species of Chrysanthemum - C. cinerariaefolium, C. roseum, and C. carneum. In this country the first of these is now the chief source of supply. The other two species were originally more important. It is best known as the active component in many proprietary household insecticides and is less frequently used under field conditions than nicotine and rotenone.

The use of pyrethrum as an insecticide apparently originated in Persia. It was introduced into Europe early in the nineteenth century and into the United States by 1860. Most of the supply of pyrethrum now used in this country is grown in Japan. In 1935 over 15 million pounds were imported (16). Pyrethrum is grown in the United States, but its place as a crop in this country has hardly passed the experimental stage.

Until 1924 the toxin was believed to be a volatile oil. The active principles are now designated as Pyrethrins I and II, which are not volatile and which kill by contact. The pyrethrins are viscous liquids which are soluble in a number of organic solvents. They penetrate the integument of insects, not necessarily through the spiracles, and cause paralysis. Apparently these toxins are harmless to warm-blooded animals. Their insecticidal activity is not accelerated by an increase in temperature as is the case with nicotine and probably they are relatively more effective at lower temperatures than nicotine. Their effectiveness is favored by a high relative humidity.

Pyrethrum insecticides are now sold either in liquid form or in powdered form. The household insecticides and those used for spraying animals are usually extracts in mineral oil, according to Gnadinger, while those used for spraying plants are made from extracts in acetone or alcohol. An oleoresin of pyrethrum emulsified with soap is also used.

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The toxic properties of pyrethrum decompose when exposed to air, sunlight, ultraviolet light, and heat. When applied as an insecticide the decomposition is very rapid. Pyrethrum powder loses its toxicity more rapidly than concentrated extracts. Cold storage from 0° to 6° C. inhibits decomposition. Household insecticides stored in tin and amber glass appeared in experiments to be particularly resistant to decomposition (15).

The place of pyrethrum as an insecticide to be used in protection of plants is not so well defined as that of nicotine and rotenone. In spite of the fact that its insecticidal value has long been recognized, it is still in an early stage of commercial development. In part this is because the insecticide is relatively expensive. It seems to be best established as a household insecticide. It is frequently recommended as a substitute for nicotine in the control of aphids, leafhoppers, and thrips, and in a few instances for the control of caterpillars. When used in the control of caterpillars, like the celery leaftier (16), its effectiveness depends upon contact the same as when it is used in the control of sucking insects. In this case its value in part depends upon its leaving no objectionable residue. It has also been found to be effective as a contact insecticide for control of the Japanese beetle (17).

Soaps

Soap has been used as a contact insecticide for many years. Prior to the advent of miscible oils and lime sulfur, practically the only contact insecticides were strong soap solutions, tobacco decoctions, and kerosene emulsion. Soap is now of importance mostly as an accessory material used as an emulsifier, or "sticker and spreader" for other insecticides. Its greatest usefulness as an insecticide is not in commercial operations but in the home garden or about the home. The advantage of using soap from the housewife's point of view is that it is easy to obtain and relatively agreeable to handle, when compared with nicotine or oil emulsions.

For use about the house the common laundry soaps are often more suitable because of their availability and lack of objectionable odors. One pound to six gallons of water is the dosage usually recommended for the control of soft bodied insects. Stronger concentrations are likely to be injurious to plants. Laundry soaps have the disadvantage of having unknown and constantly changing formulae.

Fish oil soaps are most commonly used for insecticidal purposes in the field although soaps made from vegetable oils appear to be equally effective. As a rule they can be purchased to better advantage than they can be made. The following formula, copied from Herrick, (21) will illustrate the composition and manner of making a typical insecticidal soap:

Potash Fish-oil Soap

Fish Oil	25 lbs.
Caustic Potash (not soda or lye) . . .	5 lbs.
Water.	$6\frac{1}{4}$ qts.

"Completely dissolve the potash in the water. Add the fish-oil gradually in the meantime stirring the mixture vigorously. Heat is usually necessary to fully finish the product." This is the soap usually recommended as an emulsifier in oil emulsions.

While not extensively used as insecticides in experiments, soaps appear to be useful against insects not ordinarily controlled by contact insecticides. Leach and Brinley (22) found a number of soaps quite effective as contact insecticides when used against the Japanese beetle and the rose chafer. Van Leeuwen (19), also

working with the Japanese beetle, found that the margin between effectiveness and safety to plants is narrow. Ordinary laundry soaps have been found to be effective against hemipterous insects like the harlequin cabbage bug and the squash bug. To be effective soap solutions must be applied when evaporation is low.

Aliphatic Thiocyanates

A synthetic insecticide which might replace or improve the contact insecticides derived from plants has been the subject of extensive research. The toxicity of soaps has been found to be due to the fatty acids which they contain. Crude lauric acid, commercially known as "double-distilled coconut fatty acids", was thought to embody in the greatest degree the desirable features as an insecticide of the series of fatty acids tested, and a fatty acid emulsion using this material as the active principle was developed (24). More recently certain aliphatic thiocyanates have appeared on the market which have promise of value among the contact insecticides used on growing plants (19, 20, 23).

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CHAPTER VI

INSECTS CONTROLLED BY CONTACT INSECTICIDES IN SUMMER

THE APHID PROBLEM

Aphids or plant lice* are of great interest to the biologist because of their extraordinary fecundity. For the same reason they assume importance in the eyes of the economic entomologist, for without this remarkable capacity for multiplication it is to be doubted if the group would be of great economic significance. As it is, aphids are one of the most destructive groups of insects and almost every crop plant has one or more species among its important enemies. Under favorable conditions some species of aphids begin producing young when only four days old. Each individual may produce one hundred offspring more or less, and as many as twenty or more generations may occur in a year. For example Paddock (18) found the cotton aphid** to require an average of 6.5 days to reach maturity; and that each female produced an average of 84 offspring in an average period of 21.4 days. Only once a year, just before hibernation, do most species reproduce sexually and deposit eggs. Throughout the rest of the year, all individuals are females which reproduce parthogenetically and no useless males occur. The life cycle is further shortened since with most species the nymphs are born alive and thus the time required for the egg stage is eliminated. Thus it is that aphids are able, as no other insects are, to take the maximum advantage of favorable conditions and multiply with such alarming suddenness.

Adaptations

In addition to their amazing reproductivity, aphids have other characteristics which make it possible for them to take the utmost advantage of favorable conditions, and which add greatly to their capacity for destructiveness. Insects of species which multiply so rapidly soon become crowded on the host plants on which they are living. This unusual capacity for multiplication might in itself overcome the species by exhausting the food supply. However, when colonies of aphids become crowded, winged forms appear which migrate to other plants. Wadley (7) has shown that winged individuals of the oat aphid were more numerous not only in the generation which was subjected to crowding or starvation, but also among the off-spring of the generation exposed to starvation. Clarke in California, according to Kellogg (3), was able to produce winged and wingless forms at will "by changing the chemical construction of the plants" upon which the aphids were reared. Thus under conditions favorable to them, infestations of aphids not only multiply rapidly but may spread rapidly from one field to the other and a local outbreak may assume the proportions of a general epidemic. Extreme examples of this are furnished by outbreaks of the "green bug"*** or spring grain aphid appearing in the late winter in Texas, which have in a few weeks spread over the entire wheat belt of Oklahoma, Kansas, and Southern Nebraska (8). Most aphids do not migrate so extensively as the green bug. The winged individuals do not possess the high rate of fecundity which characterizes the wingless forms. Baker and Turner found in the rosy apple aphid**** that the offspring of stem mothers on apple produced an average of 121 young each, while winged migrants produce only 18 young each (20).

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*Order Homoptera; family Aphididae

**_Aphis gossypii_ Glov

***_Toxoptera graminum_ Rond.

****_Anuraphis roseus_ (Baker)

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The production of sexual forms is sometimes regarded, like the production of migratory forms, as an adaptation to meet unfavorable conditions. According to Comstock, Slingerland reared 98 successive generations of an aphid in four years and three months, under favorable conditions in a greenhouse. During this entire period no sexual forms nor any winged forms appeared (1).

Another adaptation which enables certain species of aphids to survive adverse conditions is that they have two types of hosts, a woody plant upon which they pass the winter in the egg stage and reproduce in early spring, and an herbaceous host upon which the majority of the generations develop during the growing season. These alternating hosts are not necessarily essential hosts. As for instance, the apple grain aphid* is commonly described as passing winter in the egg stage on apple twigs. However, the species also winters on grains and grasses and on such hosts only agamic females are present. Davis (2) suggests that this is the usual form of hibernation in the South where winters are moderate and that the true sexes and the egg stage may not even appear. There are many species which are known to have only herbaceous hosts. There are also a few species which alternate between the two tree hosts, like the woolly aphid** which alternates between the apple and the American elm (5).

It may be true that most aphids do not reproduce as rapidly in mid-summer as at lower temperatures. Wadley (7) found the optimum temperature for the apple grain aphid to be 65° F., while Smith (15) also found the optimum temperature for the pea aphid to be about 65° F. There are species, however, like the cotton aphid which have a relatively high temperature optimum, and which usually occur in outbreak numbers only in late spring, in summer, or in early fall.

Seasonal History of the Apple Grain Aphid

The seasonal history of the apple grain aphid will be given as an example of those species which have alternating hosts. The alternate hosts are the apple and small grains and grass. The apple grain aphid passes winter either in the egg stage on the twigs of apple trees, or as an agamic female on grasses and grains. About the time the buds begin to show green the eggs on apple twigs hatch. These aphids on reaching maturity are known as the stem mothers. Three or four generations are produced on apple. Aphids of the second generations are wingless. Most aphids of the third and fourth generations are winged and migrate to small grains and grasses, where they reproduce agamically for the rest of the season. Aphids on grains and grasses may be either winged or wingless, depending on the abundance of food. There may be a total of 16 generations a year between egg and egg. This does not take into consideration those which continue reproducing agamically throughout the winter. With the approach of cold weather, winged males and winged agamic females are produced which fly to the apple. Here the sexual females are born. After they mate with the males, which have migrated from the summer host they deposit their winter eggs (2).

As previously indicated, in addition to the winged sexes, aphids may continue living and reproducing slowly on their grass hosts throughout the winter. Davis (2) has reared more than 60 consecutive generations of this species on wheat during a period including three winters, thus showing that the intervention of apples as a winter host is unnecessary, if winter temperatures are not too low. In the North hibernation in the egg stage probably is the rule.

In the annual life cycle just described for the apple grain aphid, the following morphological types of aphids appear, all of which differ from each other more or less, the stem mothers, the wingless agamic females, winged agamic females, sexual females and males.

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*Rhopalosiphum prunifoliae (Fitch); **Eriosoma lanigerum (Hausm.)

The control of most insects is directed against some vulnerable stage in the life cycle. Except during the period of hibernation, the life cycle of aphids shows very little variation throughout the year. One generation follows another with monotonous regularity. Since the average length of life of the common destructive aphids is about a month and they may begin reproducing in less than seven days after birth, the generations overlap. Females may be present on foliage with their children and grandchildren all producing offspring. The extent to which generations overlap is shown in a study of the clover aphid* in Idaho by Smith, whose rearing records of the first-born of each generation, beginning with the stem mother, showed 23 generations before the appearance of true sexes. The rearing records of the last-born of each generation showed that only seven generations were produced during the same period. Luginbill and Beyer in South Carolina (4) in 1913 reared 33 generations of the spring grain aphid by using only first-born nymphs, and 9 generations using only last-born nymphs.

Character of Injury

Aphids are sucking insects and injure plants by sucking their juice. This is manifested in various ways. In case of severe injury defoliation, stunting of plant growth, or killing plants outright may occur. Some species cause a distortion of the parts attacked and the form of distortion may be recognized as characteristic of the species. As for instance, among aphids attacking the apple, the green apple aphid** and the rosy aphid may be recognized by the way they curl or twist the leaves, the rosy apple aphid from the distortion of fruit, and the woolly aphid from galls formed on the roots.

Aphids consume much greater quantities of plant juices than they can utilize, and pass the partly digested excess juice through their alimentary tract. This is known as honey dew. While the chief injury caused by aphids is the reduction of vigor of the plants attacked, secondary damage may result from a heavy discharge of honey dew. On green cotton bolls a deposit of honey dew may be attacked by a black fungus which in turn also injures the boll. If the honey dew falls on the lint and then is attacked by the fungus the lint becomes discolored and is either ruined or greatly reduced in value. Ripening fruit covered by a deposit of honey dew and sooty fungus fails to color properly. Clover seeds from plants attacked by the clover aphid is usually coated with honey dew and may stick together in lumps or may even cake solidly after being placed in sacks. In some years in Idaho seed so affected brought 50 per cent less than unaffected seed (6). Honey dew is frequently attractive to ants. As a result many species of ants which feed on honey dew protect aphids from their natural enemies and care for them in other ways. The relation of ants to aphids is one of the complications in the problem of aphid control.

Natural Control

A casual reader of the foregoing may wonder how the writer will explain the failure of aphids to crowd all other life from the earth in a single season, through competition for food. One factor which may prevent this from happening is that aphids are beset by an array of enemies, both parasitic and predatory, which effectively hold them in check the greater part of the time. When these enemies fail to function, an outbreak is likely to occur. This is what is generally in mind when "favorable conditions for the development of aphids" are referred to. A more accurate phrasing might be "unfavorable conditions for development of insect enemies of aphids". An example cited by Webster is the "green bug", a pest of small grains,

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*Anuraphis bakeri (Cowen)

**Aphis pomi DeGeer

which will reproduce at a temperature of 40° F. and above. Its most effective natural enemy, a Braconid parasite, Aphidius testaceipes Cress., is hardly active at a temperature below 56° F. Consequently during mild winters and cool springs, when the temperature fluctuates between these limits, these aphids are able to multiply uninterrupted by attacks from their insect enemies. As a result they are usually more abundant in the spring, and outbreaks usually occur following a cool, wet spring.

The more important parasitic enemies of aphids are included in the parasitic Hymenoptera. The more important predatory enemies are larvae of syrphus-flies and lace-wing flies, and both adults and larvae of lady beetles.

Artificial Control

The principles involved in control of aphids are similar, regardless of the crop concerned. Usually the end sought is merely a reduction of the number of aphids until natural conditions can take care of the situation. It is true that the farmer may expect complete eradication when he sprays with nicotine sulphate for aphid control, and frequently thinks he gets it when weather conditions are such that the aphids suddenly disappear. On the other hand, he is inclined to complain of the ineffectiveness of the insecticide when in a week or ten days after spraying the aphids reappear in large numbers, either because of a multiplication of survivors or an immigration from neighboring orchards or fields.

The application of insecticides on field crops for aphid control is not usually recommended on account of expensiveness. Such measures as are recommended are largely measures of prevention or measures intended to aid their natural control. These measures include pasturing to mechanically destroy or expose aphids attacking forage crops, the use of brush drags and chain drags, and the destruction of volunteer hosts or alternate hosts. These methods may be classified as mechanical or cultural control. Only insecticidal control will be discussed here.

Control with Insecticides

Nicotine sulfate is the spray material most frequently used in the control of aphids. If applied in liquid this is a contact insecticide and it is necessary to hit the insects to be controlled. The problem of timing applications may be simple enough provided the species is like the apple-grain aphid on apple which feeds on the under sides of foliage, or like the brown grape aphid which sucks sap from the terminal shoots. These insects are continuously exposed and spraying to control them may be done at any time provided they are abundant enough to justify it. If nicotine sulfate containing forty per cent nicotine is used, a dosage of one pint in 100 gallons of water plus two pounds of soap as an activator and spreader is usually recommended.

The control of aphids, however, is not always simple. Aphids are often protected by foliage distorted by their feeding, or by galls. They may be destructive at times when the temperature is so low that nicotine is not active. Certain species are protected by waxy secretions which prevent penetration of the insecticide.

THE PEA APHID

The control of the pea aphid* by insecticides is typical of the control of many other aphids. In addition to peas this insect is a pest of a number of other leguminous crops, including alfalfa, red clover, crimson clover, and vetch. In the

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*Illinoia pisi (Kalt.)

North it passes winter in the egg stage on the stems of its perennial or winter hosts. In the South, active aphids may be found on alfalfa and vetch throughout the milder winters. The damage which it causes usually occurs in the earlier part of the season. The injury is either direct, by removing sap from the plants, or by the transmission of disease. At times the injury is so severe it may practically destroy the pea crop, or the first cutting of hay on its forage crop hosts. If alfalfa or vetch is grown in the vicinity of peas, migrations of aphids from the forage crops to peas makes direct control on the latter more difficult. In this discussion attention will be limited to direct control on peas.

A choice of two insecticides in a total of four forms of application were recommended for pea aphid control by a group of entomologists at the annual pea aphid conference in 1939 (12). These insecticides are: (a) derris or cube dusts, containing one per cent rotenone, in a mixture including talc and a conditioning agent; (b) nicotine dust containing 4 per cent nicotine; (c) nicotine vapor; (d) derris or cube spray, using 3 pounds of ground derris or cube containing 4 per cent rotenone to 100 gallons. Corresponding dilutions should be used if the derris or cube contains a different concentration of rotenone. A spreading agent is necessary.

If nicotine dust or nicotine vapor is used the duster should be followed by a canvas trailer 100 feet long, and the vaporizer should not travel faster than 100 feet a minute. If a rotenone bearing dust is used a 25 foot trailer should follow the duster and the rate of speed should not exceed 300 feet a minute. Dusts are usually applied at the rate of 35 to 40 pounds to the acre. Spraying requires 125 to 200 gallons to the acre. If nicotine vapor is used, about 3 pounds of a liquid containing 80 per cent free nicotine is required to the acre (12).

The amount of nicotine included in the dust mixture is higher than the amount usually recommended for the control of aphids during summer. The relatively low temperatures which occur in the spring at the time the applications are made in part are responsible for this. The addition of a wetting agent to the spray mixture is of importance in increasing adhesion to the waxy foliage and stems of the plant. Spraying with rotenone bearing insecticides has been found to be more effective than dusting (11, 15) but dusting is recommended for growers who do not have adequate water supply or equipment available.

The number of insecticidal applications necessary for control of the pea aphid is usually one or two if properly timed. To prevent unnecessary expense, obviously it is desirable to hold the number of applications to the minimum. On the other hand, delay in treatment may result in unnecessary damage. The pea aphid conference recommended that an insecticide be applied when an average of 35 aphids were collected at a single sweep of a net (12).

The number of aphids which may cause serious damage depends in part upon the age and size of the plants. Peas tend to become relatively uncongenial hosts for the pea aphid as the plants approach maturity. For this reason if the infestation is destroyed about the time peas come into blossom, aphids cannot increase rapidly enough to reach destructive numbers that season, according to Searls (13). Making counts at definite intervals throughout the season has been suggested by Glasgow (10) for regions where peas are an important canning crop, as a means of determining when insecticidal applications should be made. The number of aphids present on plants of various sizes to cause slight, moderate, or severe injury are shown in Table 1. The counts are based on 10 sweeps of an eleven inch collecting net.

Table 1. Aphid population in relation to crop damage to peas based on counts of aphids collected by ten sweeps of a net (Adapted from Glasgow).

Height of plants	Degree of infestation and number of aphids			
	Slight*	Moderate	Severe	Ruined
Small 1" - 5"	25 - 100	100 - 300	300 - 1000	1000 - 4000
Medium 6" - 12"	100 - 300	300 - 1000	1000 - 4000	4000 -10,000
Large, over 12"	300 - 1000	1000 - 4000	4000 - 10,000	10,000-50,000

*Aphid populations in less number than "slight" are classed as "trace of infestation".

The accuracy of such counts as indicators of probable injury is shown by comparing these ratings and the yields of 10 typical pea fields in New York during the seasons of 1936-1938. In five fields in which the infestation was rated as ruinous at the time of the peak of infestation, the average yield was 323 pounds of peas to the acre. For one field where the aphid count was 64,000 at the peak of infestation, the yield was only 6 pounds. On the other hand, in a single field where the infestation was rated as slight the yield was 2,995 pounds to the acre.

THE COTTON APHID

The cotton or melon aphid is one of the more important plant lice of the South. Cotton, melons, cucumbers, squash, and citrus trees are the hosts on which damage most frequently attracts attention. Sixty-four hosts have been listed from Florida (17). The hibernating stage has not been found in the South, but in Maine winter is passed in the egg stage on live-for-ever (Sedum purpureum) (19). As many as 51 generations have been reared in a single year in Florida (17).

Injury to cucurbit crops and to cotton usually occurs in summer. The infestation is most readily observed when aphids are abundant enough to cause curling of the leaves. Outbreaks on cantaloupes and watermelons may kill stands outright or materially reduce the yield. On cotton the indirect injury from honey dew which drops on the bolls and lint may be more serious than the direct injury. The most severe injury to cotton usually follows a succession of dust applications of calcium arsenate for boll weevil control. It has been assumed that calcium arsenate represses the natural enemies of aphids. Recent work has indicated that dusting with calcium arsenate may increase the pH. of the cell sap and that this change is favorable to the cotton aphid (16).

While aphids protected by twisted leaves cannot be hit with a contact spray, they can be killed by rapidly volatizing nicotine. Nicotine volatilizes most rapidly when applied in dust with an alkaline carrier like hydrated lime, and the action is most rapid when temperature is high. During hot summer weather with a temperature of 90° F. or more, a dust carrying as little as one per cent nicotine has destroyed 100 per cent of the melon aphids on cantaloupes in experimental plots in Arkansas. The same species on cotton plants about four feet high dusted under the same temperature conditions were not as completely destroyed by a two per cent dust. Probably the concentration of gas around the upright plants is less dense than it is just over the ground. Also the effect of radiation of heat from the hot soil was a factor. A canvas trailer dragged after the duster increases the effectiveness of

the nicotine. Recent experiments have shown that a dust containing 0.5 per cent of rotenone is effective in killing the cotton aphids which it actually hits. To be effective it is necessary to set the duster spouts so that they will blow the dust upward and cover the undersides of the foliage.

THE ROSY APPLE APHID

The rosy apple aphid is an example of one of the leaf twisting forms which present a problem of control in which timing is of first importance. This aphid is often a first rate pest of the apple. The evidence of injury is twisted foliage, clusters of stunted and distorted fruit, and stunted terminals. This injury is most severe in the lower part of the tree. Winter is passed in the egg stage around bud scales and in crevices of twigs of the apple. The eggs hatch when the tips of the buds are showing green. By the time apples reach the cluster bud stage the infested leaves on which the stem mothers occur may be twisted to such an extent that it would be impossible to hit a large proportion of them with spray. From this time on until the aphids leave the apple tree in early summer for their herbaceous host, the long leafed plantain, the majority of them are protected by the twisted foliage. They return in late fall and the sexual females again deposit the winter eggs on the twigs.

Thus, there are only two periods in the seasonal history of the rosy aphid when it may be hit by a contact spray, the long egg stage on the twigs during the dormant season, and the very short period in the spring between the time of hatching of the stem mothers and of twisting of the foliage which they attack, when the buds are first showing green.

Control during the egg stage involves dormant spraying. Unfortunately the oil emulsions which are the insecticides most commonly used in dormant spraying for control of scale insects are not effective in destroying aphid eggs. During the past few years the tar oil emulsions and DN have been found to be effective as ovicides for aphids. Tar oil emulsions and DN are not satisfactory, however, for the control of those armored scales like the San Jose scale. Therefore, if these winter ovicides are to be used alone they may involve making an extra dormant spray. Usually it is recommended, however, that one of them be applied in combination with dormant oil emulsion for control of the San Jose scale as well as for the rosy aphid. If tar oil is used, it should be added at the rate of 2.4 per cent to 2 or 3 per cent of lubricating oil in an emulsion. If DN is used, 4 parts should be included in 96 parts of oil before emulsification. These insecticides must be applied when the buds are in the gray stage and before they show green (21, 22, 23).

To destroy the newly hatched stem mothers a spray of nicotine sulfate containing 40 per cent nicotine may be effective. This material is used at the rate of one part to 800 in lime-sulfur applied at summer strength of three parts in 100 (22, 24). The lime-sulfur is of value chiefly as an activator, in breaking down the nicotine. Since temperatures are usually relatively low when buds are opening, the dosage of one to 800 alone, which is effective against most aphids in summer, would not be effective at early spring temperatures. Spraying at this time has a further handicap in that the optimum period during which applications should be made, that is after the buds begin to show green and before the leaves begin to curl, is very short, often as short as two days, and bad weather may intervene.

The abundance of the rosy aphid may also be affected by destroying its summer host.

CONTROL OF LEAFHOPPERS

The control of leafhoppers* resembles that of aphids in that both are easily killed if a susceptible stage is hit by a satisfactory contact insecticide. Probably the same insecticides are effective against insects of both groups. The important difference in the problem presented, however, is that leafhoppers do not have a continuous succession of overlapping generations. In fact the leafhoppers which are controlled by insecticides seldom have more than two or three generations a year, and only the nymphs are readily susceptible to control by spraying. Hence the time of making spray applications must conform to the seasonal occurrence of the nymphal stage. Success in control of leafhoppers depends more upon a knowledge of the time of occurrence of generations than it does in the case of aphids.

One of the leafhoppers attacking apples, the white apple leafhopper**, will serve to illustrate the problem of control of insects of this family. Both adult and nymphal stages feed on the under sides of the older apple leaves and are usually most evident on the lower half of the trees. The injury is readily recognized by the whitened appearance of the leaves. When infestations are heavy they cause a partial defoliation late in the season, and doubtless reduce the carbohydrate formation, and in the end reduce the amount of sugar carried to the fruit and fruit buds. Under such conditions the upper sides of fruits may be covered by excrement which is attacked by a sooty fungus and which injures the color and finish. Leafhoppers are usually considered as second rate pests on apples, and are erratic in occurrence in outbreak proportions. Since they do not cause a definitely determinable damage to the fruit, measures for their control are usually neglected. The species appears to be favored by the usual spraying program because fungicides tend to repress its most important fungous enemies (28).

The white apple leafhopper has two generations each year with no overlapping of the active stages of the two generations. Adults of the first or spring generation all die before the appearance of nymphs of the second or late summer generation. The insect hibernates in the egg stage. The winter eggs are laid singly during the early fall under the bark of the young wood where they appear on the twigs as tiny raised blisters. About apple blossoming time of the following year the eggs hatch. The entire hatching period may continue over two weeks, although the majority of the eggs hatch within four days. Eggs for the second generation are deposited in the leaf tissues of the undersides of the lower leaves, during May and June. The eggs that are to overwinter are deposited in the latter part of September and during October.

The seasonal history at Bentonville, Arkansas, in 1925 will illustrate the occurrence of susceptible stages and the sequence of generations (26). Nymphs of the overwintered generation were found on apple foliage from April 10 to May 28, and the adults of this generation were present from April 24 to June 12. The first summer eggs were deposited about May 5, and hatching occurred from July 22 to September 15. From June 12 to July 22 no active stages of the insect were present either in cages or in the field. Second-generation nymphs or adults were present on apple from July 22 to November 2.

Both generations of the white apple leafhopper have very long egg stages and a comparatively short nymphal and adult stage. The average of the incubation period of the summer eggs was 74.6 days. The entire nymphal period in 1925 required an average of 19.8 days. In more northern fruit districts the summer egg stage is considerably shorter than in Arkansas (26). At West Chester, Pa., for instance, the

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*Family, Cicadellidae

**_Typhlocyba_ _pomaria_ McAttee

[illegible]

[illegible]

[illegible]

[illegible]

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[illegible]

[illegible]
[illegible]
[illegible]

incubation period for summer brood eggs ranged in 1916 from 23 to 27 days (25). In this way the seasonal history of the species is adapted to the shorter summers of the North.

The control of all leafhoppers on apple which do not curl the foliage is similar. When in the nymphal stages they can be killed by spraying with nicotine sulfate even more easily than aphids. A dosage of 1 to 1600 in lime sulfur, or in Bordeaux mixture plus one pound of soap to each 50 gallons of spray mixture, is sufficient to kill every leafhopper nymph which is actually hit. If the nymphs exceed in number 5 to a leaf, Garman recommends that a dosage of nicotine of 1 to 800 be used (27). Since these leafhoppers do not curl foliage they are easy to hit if attention is given to spraying the lower sides of leaves. The adults cannot be controlled by spraying. Consequently the spraying problem resolves itself into timing applications to destroy nymphs. Usually a single spray application will destroy enough first generation nymphs to prevent increase to destructive numbers that season. This application should be made when the oldest nymphs of a generation are nearly grown, for at this time the majority of the eggs will be hatched, and the generation can be nearly exterminated by a single application. The exact time of the year when nymphs of the first generation occur can be predicted only in a general way, since it depends somewhat upon climatic conditions. However, the nymphs can be easily seen, and their abundance estimated, and, therefore, remedial measures can be timed easily, provided occasional observations are made during the period when they are expected to be present.

SUMMARY

The variations in the problem of insecticidal control of the three species just discussed indicate the extent to which the control of aphids may differ. The pea aphid is most readily hit by insecticides, but on account of the relatively low temperatures during the season when outbreaks occur, increased dosages of nicotine are necessary if this insecticide is used. The waxy foliage of the host also necessitates the use of a wetting agent if a liquid spray is used. Timing applications is not important in determining the effectiveness of control since this aphid can be hit at any time, but it does determine the number of applications necessary. Careful timing is therefore advisable to avoid excessive cost.

The melon aphid might be expected to be difficult to control since it is protected from direct contact with spray mixtures by the distorted foliage. Its control is relatively easy, however, because outbreaks occur during hot weather and its hosts grow relatively near the ground where the fumes of rapidly volatilizing nicotine can be concentrated.

The rosy apple aphid cannot be controlled by a contact insecticide when once protected by twisted foliage. Its control depends on spraying in the brief interval after the stem mothers hatch on the green buds and before distortion of foliage begins, or in resorting to dormant spraying to destroy the eggs. If the first method is used, timing in relation to seasonal history is essential.

All of the various contact insecticides discussed in the previous chapter have been recommended at some time for the control of aphids. Nicotine is most commonly used with rotenone as the most frequent replacement. Pyrethrum is not as frequently used, partly because of cost. Kerosene in an emulsion at a 10 per cent dosage has also been recommended. At one time kerosene emulsion was the chief dependence for aphid control. The cost of the kerosene and soap, however, is usually greater than the cost of an equally affective dosage of nicotine, the chance of plant injury is greater, and the inconvenience of making the emulsion is also of consideration. Kerosene emulsion may still have a place in an emergency when a better insecticide cannot be secured. For controlling aphids in the egg stage DN in oil is the most frequently used.

The white apple leafhopper when in the nymphal stage can be destroyed as easily as aphids, if it is hit with a contact insecticide. More careful timing is necessary, however, since only the nymphal stage is accessible to control. Nicotine sulfate is the insecticide most commonly used.

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CHAPTER VII

MISCELLANEOUS CONTACT INSECTICIDES AND ACCESSORIES

SULFUR AND SULFUR COMPOUNDS

The greatest usefulness of sulfur and various sulfur compounds as insecticides is in the control of the various species of Acarina. This statement applies not only to those mites which are destructive to plants, but to those which are pests of animals like the scaly-leg mite of poultry, the sheep scab mite, and the itch mite. Besides use in the control of mites, sulfur has a limited field of usefulness against various sucking insects. At present the control of the cotton fleahopper utilizes large amounts of sulfur. It is also used as a carrier for various insecticides which are applied in dust form.

Lime Sulfur

Lime sulfur is the best known of the sulfur compounds. This is probably because it was formerly the most important insecticide used in dormant spraying of deciduous fruit trees. With the advent of lubricating oil emulsion in the field of San Jose scale control, lime sulfur has almost disappeared as a dormant spray material. It still has a limited use for the control of scale, however, particularly on peaches since at the same time it may be effective in the control of peach leaf curl. It may also be applied for the control of blister mite on pears and apples (5), and is used as a summer spray for the control of mites on citrus (6). It is employed now more as a fungicide than as an insecticide, and the entomologist more frequently comes into contact with lime sulfur in combinations of fungicides and insecticides, rather than with it as an insecticide alone.

Lime sulfur is prepared by boiling lime and sulfur together in water. Several chemical combinations are thus produced but apparently the insecticidal value depends upon the calcium polysulfids (CaS_4 and CaS_5) and possibly upon calcium thiosulfate (CaS_2O_3). A typical formula for lime sulfur is as follows:

Stone lime (90% or more CaO)	50 lbs.
Sulfur	100 lbs.
Water.	50 gals.

Lime sulfur can be home made, but in most cases it is easier to buy the stock solution and dilute as needed. Directions for making are given in most of the common manuals (3, 5).

Lime sulfur, originally a sheep dip, was first used in controlling the San Jose scale in 1886 in California. It did not come into general use for this purpose until after 1900 (5). Its usefulness as a summer spray and as a fungicide were later developments.

As a dormant spray for the control of the San Jose scale, lime sulfur should be used at a dosage of one part to seven parts of water. At best it is not effective at low temperatures, and reaches its maximum effectiveness only in spring shortly before the buds open. The chief factor in its being superceded by oil emulsions, however, was that in certain localities the San Jose scale apparently developed resistance to lime sulfur. Lime sulfur is caustic and disagreeable to handle. For the control of blister mite, a dosage of one to 11 is recommended.

When used during the growing season as an insecticide on deciduous fruits, the dosage should never exceed three gallons to 100 of water. This dosage will cause

serious injury if the temperature is high. On citrus trees, where it is used for the control of red spider and rust mite, Yothers (6) recommended a dosage of one to 75.

Lime sulfur cannot be used with safety as a summer spray on certain plants, notably peaches, grapes, and potatoes. It should not be used in combination with soap or with oil emulsions except under special conditions.

Sulfur

Sulfur in the form of very fine powder is used for the control of the cotton flea hopper and other mirids. How sulfur kills is not definitely known, although it is believed that the rapidity of its volatilization is a factor, since the efficiency seems to depend upon temperatures and upon the relative fineness of sulfur. Even the finest grades of sulfur are not effective as insecticides below 75° F., while above 90° F. their efficiency is increased. It is also essential that sulfur be of sufficient fineness that it will pass through a screen with 300 meshes to the inch.

Sulfur has also been used for the control of red spider and other mites. More recently it has been used for control of the red spider on cotton as a carrier for DN. Sulfur is frequently used as a diluent for other insecticidal dusts.

MERCURY COMPOUNDS

Certain compounds of mercury have a limited use as insecticides. Corrosive sublimate (mercuric chloride) is best known as a disinfectant and is little used as an insecticide. However, a 1-1000 solution is effective in the control of certain root maggots, and it has been sometimes recommended as a repellant for ants. According to Gibson (2), early references in literature indicate that the insecticidal value of mercuric chloride has been known for 50 years. However, its use was not generally recognized until results of work in Canada were published in 1919.

Calomel (mercurous chloride) has been recognized as an insecticide more recently and has largely replaced the use of the corrosive sublimate in its specialized insecticidal use for root maggots.

INSECTICIDAL ACCESSORIES

Materials are frequently added to insecticides to increase their effectiveness. This increased effectiveness may be the result of increased adhesiveness, better spreading quality, or increased activity of the insecticide. These insecticidal accessories are referred to as wetting agents, stickers, or activators. Many of them have insecticidal properties of their own.

The need of an added material is most obvious when an aqueous suspension of an insecticide is applied to the waxy foliage of a cabbage plant or to a cluster of green grapes. Without the addition of a proper wetting agent the greater part of the spray material will run off. Many insects are not readily wetted with an aqueous spray, either because of the character of the chitin or because of a covering of fine hairs (1). A wetting agent is important in such cases, particularly to increase the efficiency of contact insecticides. The resistance to weathering of an insecticidal deposit on foliage may also be greatly increased by the accessory material applied with it. The use of soap or calcium casienate with nicotine sulfate to break down the sulfate and free the nicotine has already been discussed and illustrates an accessory used as an activator. The use of excessive amounts of

some of the wetting agents which are effective because they lower the surface tension may actually reduce the efficiency of the spray mixture if the run-off is increased unduly (4).

Soaps and oil emulsions are most commonly used with other insecticides to increase their effectiveness. They may be useful in increasing the adhesiveness of certain stomach poisons and in adding to the penetrating properties of contact insecticides. Soaps and oil emulsions have a limited usefulness because they are incompatible in certain combinations of spray materials. For years various colloidal materials like calcium casienate, glue, soybean flour, and vegetable gums have been recommended to increase the spreading qualities of insecticides. More recently various sulfated and sulfonated compounds used in the textile industry have come into use as wetting agents for insecticides. Among this last group are sodium lauryl sulfate and butylphenylphenol sodium sulfate (1). Sometimes these materials are added as conditioning agents to insecticides in dry form to increase their miscibility with water, or to increase their efficiency when applied as dusts.

Reference to these insecticidal accessories appear in connection with the discussion of insecticides with which they are applied.

THE COTTON FLEA HOPPER

The cotton flea hopper* feeds upon the terminals of rapidly growing cotton plants and upon tiny squares, killing the parts attacked. As evidence of such injury the plants fail to set fruit. On such plants one may find blasted squares which become nearly black and hang on the plants for a few days after the injury first occurs. Where the terminal buds are killed, a number of new terminals are thrown out giving the plants a bushy top. Where the terminals are not killed and the stripping of squares is continued, the plants grow very tall without well developed branches. Similar injury is caused by two other leaf bugs**, the cotton leaf bug***, and the tarnished plant bug****, except that these mirids will attack larger squares than those injured by the cotton flea hopper.

The extent of damage caused by the cotton flea hopper is exceedingly variable from year to year. While the pest occurs throughout the cotton belt, it appears to be more destructive along the Gulf Coast of Texas than elsewhere. It causes some damage nearly every year, however, even as far north as northeastern Arkansas.

Cotton is the only crop plant which the flea hopper injures. It has a number of weed hosts, however, which are of importance as sources of infestation. Among these other hosts from which infestations most frequently arise are croton or goatweed, horsemint, evening primrose, ragweed, and bitterweed (8, 9, 10).

The cotton flea hopper is only about one eighth of an inch in length. It is pale greenish in color and is marked with minute reddish brown dots. The eggs are flask-shaped and are about one thirtieth of an inch long. They are deposited in the tender tissue just under the epidermis. In mid-summer about eight days are required for the eggs to hatch and about ten days more are necessary for passing through the five nymphal instars. Thus in about 18 days the cycle from egg to adult may be completed.

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*Psallus seriatus Reuter

**Family, Miridae

***Adelphocoris rapidus Say

****Lygus pratensis (L.)

Winter is passed in the egg stage. There are a large number of generations a year, but since these generations overlap, there is no distinct break between them. Adults and nymphs of all sizes may be found at any time during the summer. During the early part of the season the flea hoppers feed on weed hosts that happen to be growing at that time. As these hosts approach maturity, the flea hoppers migrate to others and often to cotton. As a rule infestation of cotton fields takes place before fruiting begins and breeding on cotton continues as long as succulent growth is available. Flea hopper injury usually declines markedly within a month after cotton squares begin forming, although in some fields it may continue until frost.

The destruction of squares formed early in the season may be recovered during the latter part of the summer if conditions are favorable. If, however, there is late injury by other cotton pests, the loss of the early crop may be serious.

Outbreaks of the cotton flea hopper are more severe during years when there is an unusual amount of rainfall during the early part of the growing season (9). The injury continues longer in cotton grown on heavy soil than on light soil and also longer on varieties that fruit over a long period than on the rapidly maturing determinate varieties.

Control

The cotton flea hopper can be controlled by dusting with sulfur, ground so finely that 93 to 95 per cent will pass through a screen with 325 meshes to the inch. The first application should be made when it is evident that injury is occurring. Sulfur should be applied at the rate of 10 to 20 pounds to the acre, depending upon the size of the cotton plants. Sulfur is more effective against the nymphs than against the adults. One or two applications of sulfur are usually enough to stop injury in Arkansas (9) while in Texas as many as five applications are sometimes necessary (10).

THE CABBAGE MAGGOT

In the dipterous family Anthomyiidae, there are a number of species whose larvae are injurious to roots of various crops. Among these the cabbage maggot* is best known. It is a pest of European origin, presumably, and is most injurious in northern latitudes. It was first reported from Germany in 1833 by Bouche and from America in 1835 by Harris. In Europe it is reported as being most destructive in Germany, England, and the Scandinavian countries, while in America it is of most importance along the northern border of the United States and Canada. It also occurs in Alaska. It is probable that the optimum conditions for this pest coincide with the optimum conditions for its preferred host, cabbage.

The cabbage maggot will breed upon a wide range of cruciferous plants, but its favored hosts are cabbage in its various forms, including cauliflower, collards, brussels sprouts, etc., and radishes and turnips. Its chief injury is to seedlings in the seed bed and to early cabbages in the field. Most of this injury is caused by the larvae of the first generation (15).

The young maggots feed upon the main root, working their way downward. Injury at this stage is caused by rasping out a channel on the surface. When deep in the soil they attack the tender rootlets and later burrow into the main root. Sometimes they attack the stem above ground, and even the midrib of the leaf. Usually the first indication of injury to a cabbage plant is the tendency of the plant to wilt

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*Hylemyia brassicae (Bouche)

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in the heat of the day. Roots badly riddled with their burrows decay and death to the plant quickly follows (15). The cabbage maggot passes winter in the pupal stage in the soil. Flies emerge in spring about the time of blooming of Windsor cherries (the middle of May in New York), and continue emerging for about one month. Eggs are deposited in the soil near the stems of the host plants. In New York the eggs hatch in four to ten days, the larval period is about three weeks, and the pupal period three. Thus a total of about six weeks is required for the immature stages. A total of three generations and a partial fourth occur annually in New York (15). Pupation occurs in the soil an inch or more away from the plant.

Control

For years, control depended upon cheesecloth coverings for seed beds and tarred paper protectors for plants. Recently, however, these practices have given way to treatment with corrosive sublimate. The use of the mercuric compounds is cheaper, more effective, and does not induce disease (14). Corrosive sublimate was recommended as a control for this pest early in 1864, but it did not come into general use, probably because the importance of timing applications in relation to seasonal history was not recognized. It may be a repellant and will kill young larvae (12). It will not destroy an established infestation. Consequently applications must be made before injury is apparent (12). For the control of the cabbage maggot, corrosive sublimate used at the rate of one to 1200, or one ounce to ten gallons of water, has given good results (2, 12). On seed beds a single application requires about one gallon of dilute mixture for 20 to 40 feet of the row. One gallon is enough for 30 plants set out in the field (14).

The use of calomel (mercurous chloride) was developed following the recognition of the value of mercuric chloride. It may be applied in the same manner in water, at the rate of one ounce in ten gallons. It may also be applied in dust using four per cent calomel in 96 per cent gypsum which may be applied by drilling in the seed row or coating the seed (13).

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CHAPTER VIII

FUMIGANTS AND CONTROLLED TEMPERATURE

Fumigation may be used in insect control provided the fumigant can be confined to the space occupied by the infested material. The commonest insecticidal uses of fumigants are to control (a) insects infesting seeds or milled products in storage; (b) insects on growing plants in greenhouses, or on plants which can be covered temporarily at least by canvas; (c) against soil inhabiting insects; and (d) against household pests. In the case of soil inhabiting insects, the soil prevents too rapid diffusion of gas.

When a fumigant is used to control insects on living plants, it competes with contact insecticides. It has an advantage, however, in that actually hitting the insects is unnecessary. The disadvantages are that the chances of injury from those fumigants which can be used on growing plants are much greater than with most contact insecticides. Furthermore, fumigation is relatively expensive.

High or low temperatures are used frequently as substitutes for fumigation in insect control. The use of temperature usually has the same limitation as fumigation since it also must be confined, unless the high temperature is carried by hot water.

General Considerations and Precautions

The success of fumigation depends, in part, upon the tightness of the building or enclosure in which the fumigant is liberated. Wind reduces its effectiveness. High temperature favors the efficiency of a fumigant, since it increases chemical activity and also increases the respiratory rate of insects. A temperature of 60° F. or above is sometimes considered necessary although the lowest effective temperature varies with the fumigant, and the efficiency of fumigation increases with an increase in temperature. With most fumigants it is desirable to secure the highest possible concentration of gas soon after the fumigation is begun. In warehouses which are loosely constructed a rubberized tarpaulin can be used to confine gas for treating individual stacks of supplies. The ordinary canvas tarpaulins are not satisfactory for this purpose (26).

Handling the more dangerous fumigants like cyanide and chloropicrin is usually a job for the professional fumigator. When working with these fumigants on any extensive scale the operator should be equipped with a gas mask and should be acquainted with the limitations of the mask used. In all cases he should be familiar with the plan of procedure before he begins fumigation. There should be an extra man to watch the operators and to give assistance when necessary. Help at the right time may prevent fatal accidents. A building which is being fumigated should be posted with warnings and in some cases the employment of a watchman to prevent accidental entries may be advisable. After fumigation the building should be thoroughly aired before using. There is a danger in ventilating as well as in applying the fumigant and in this procedure also two or more men should work together so that accidents may be avoided.

Carbon Disulfide

The use of carbon disulfide on the farm is perhaps more general than that of any of the other fumigants. This is particularly true on the farms in the South where the use of the other insecticides for fumigation is scarcely known. It is the simplest to use and is probably, all things considered, the most effective for treating bulk grain (7). For many years it was the only fumigant used in the control of grain insects even in elevators and cars. On account of the fire hazard which accompanies its use, carbon disulfide alone has been almost entirely replaced except on

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the farm. It is sometimes used in a mixture of one part of carbon disulfide with four parts of carbon tetrachloride which is relatively free from fire hazard.

Carbon disulfide is a colorless liquid when pure although the commercial chemical is often yellowish due to the hydrogen sulfide which it contains. It is about one-forth heavier than water. The gas is 2.63 times as heavy as air. The boiling point is 114.8° F. (7).

The dosage of carbon disulfide required to kill insects in stored grains in a tight bin is eight pounds for each 1,000 cubic feet of space. In cribs 20 to 40 pounds to 1,000 cubic feet is usually recommended and this is only relatively effective (6). The time required for fumigation is from 24 to 48 hours. It will injure the germinating quality of seeds which are not dry at time of fumigation, and should not be used with certain seeds rich in oil (16).

The problem in regard to fumigation of grain on the farm in most of the southern states is not one of dosage, but one of buildings suitable for fumigation. Because of this, extensive fumigation is not generally resorted to. Seeds such as cowpeas are fumigated in cans or barrels and a few seed growers have fumigation bins built in connection with their seed storage houses. As a rule this type of insect damage to grain on the farm is taken without protest.

The most frequently mentioned disadvantage in the use of carbon disulfide as a grain fumigant is that it is explosive and inflammable. This may not be considered a handicap in fumigating small amounts of grain where the grain is not stored in barns or in connection with other buildings. The most frequent causes of fire when this insecticide is used are carelessness by smoking or carrying a light in a building where gas is confined. Grain which is heating should not be treated with this fumigant (6).

Carbon disulfide has been recommended as a soil fumigant for controlling agricultural ants, and for the control of the grape phylloxera. It has been tried experimentally for the control of insects attacking the roots of many plants, but injury has invariably been severe. Its effectiveness in a mechanical mixture with water as a means of destroying the woolly aphid was demonstrated by Leach (18). None of these uses has become general in the United States. More recently an emulsion which may be used with safety on lawns and golf greens was developed as a soil fumigant for the control of grubs of the Japanese beetle and other scarabaeids. As in the case of lubricating oil emulsions, two types of emulsion have been developed. One is suitable for a commercial emulsion, since it does not stratify on standing (19).

Carbon Tetrachloride

Carbon tetrachloride has been recommended sometimes as a substitute for carbon disulfide. The chief reason for its recommendation is that it is non-inflammable. It is also heavier than air. It is not an effective fumigant when used alone. Its chief value is as a diluent for carbon disulfide and ethylene dichloride to reduce the fire hazard.

Chloropicrin

Chloropicrin, a "tear gas", has been used experimentally for fumigation of clothing to destroy body lice (21) and more recently has come into use as a mill and elevator fumigant (11, 27). It is a colorless or slightly yellowish liquid, weighing a little more than one and a half times as much as water. It volatilizes

slowly, and the gas formed is about five times as heavy as air. As ordinarily used, it is non-explosive and non-inflammable. Because it is extremely irritating to the eyes and respiratory passages, any one accidentally entering a building which is being fumigated, will be effectively warned to stay out. The dosage recommended for use in grain in an elevator is two to three pounds to 1,000 bushels. The liquid is poured into the grain stream as it is run into the bins. Chloropicrin is an insecticide to be used only by a professional fumigator (4).

Ethylene Oxide

Ethylene oxide is an insecticide which first received attention in 1928 (3). Commonly it is used mixed with carbon dioxide at the rate of one pound of the former to nine of the latter. It is useful as a fumigant for foodstuffs of all types because the materials treated seem to be free from obnoxious odors and residues (3), and because it may be used with little injury at ordinary temperatures even to ripe fruits like the raspberry and strawberry. As for instance, it has been recommended for the control of the Japanese beetle in cars of ripe fruit at a dosage of 2 pounds to 1,000 cubic feet maintained for 2 hours at 75° to 80° F. (22). A further advantage is that this insecticide kills first the rapidly dividing cells, and for this reason kills eggs which usually escape other forms of fumigation (15, 17). An ethylene oxide-carbon dioxide mixture is also recommended for the protection of fabrics and for the control of grain pests in elevators.

The properties of ethylene oxide have been described as follows: At ordinary temperatures ethylene oxide is a colorless gas; at low temperatures it is a mobile liquid that boils at 50.9° F. The specific gravity of the liquid is 0.887. In concentrations up to 3.5 pounds per 1,000 cubic feet, it is non-explosive and non-inflammable. It has a faint but distinct ether-like odor. The vapor is approximately 1.7 times as heavy as air and exhibits remarkable penetration into compact materials. While not highly toxic to man the vapor of ethylene oxide should not be breathed extensively (22).

The relative safety of ethylene oxide to the operator, and to products usually injured by fumigants recommends it. The cost is somewhat higher than carbon disulfide. The greatest disadvantage for common use, however, is that it is so highly volatile that it must be stored in steel cylinders and cannot be handled conveniently by the non-professional operator.

Carbon dioxide is frequently recommended as a diluent for ethylene oxide. It also increases the efficiency of the fumigant because of its effect upon the respiratory action of the insects (8).

Ethylene Dichloride

Ethylene dichloride - carbon tetrachloride mixture including three parts of the former with one of the latter is the most commonly recommended substitute for carbon disulfide for fumigation of stored products wherever fire hazard is a consideration (9). It also has a place as a household fumigant. The inclusion of carbon tetrachloride renders the fumigant practically non-inflammable and non-explosive.

Ethylene dichloride is also used in an emulsion as a soil fumigant. The emulsion is made by stirring nine parts of the fumigant into one part of a potash fish oil soap containing 30 per cent oil (26).

Ethylene dichloride is a colorless liquid with an odor similar to that of chloroform. Upon exposure to air it evaporates slowly. Its boiling point is 182.7°F. The gas is over three times as heavy as air. It is only slightly inflammable, non-injurious to stored products, and not dangerous to human life. It has an anesthetic effect if breathed in concentrated form (7).

Paradichlorobenzene

Paradichlorobenzene is a colorless, crystalline substance, which volatilizes readily on exposure to air. The gas given off is heavier than air, and like carbon disulfide penetrates soil or masses of grain. The gas is non-inflammable, and is not injurious to man or animals. It volatilizes slowly at ordinary temperatures. Its boiling point is 341.6° F. This factor is of importance when protection over a long period is desired.

The use of paradichlorobenzene as a fumigant for grain was given experimental trial by Duckett (12). It has never come into general use for this purpose since an objectionable odor persists in flour made from grain fumigated with it. The objectionable odor also occurs in meat of animals fed upon grain treated with this fumigant. Blakeslee (5) demonstrated its value as a soil fumigant to be used in the control of the peach tree borer. This work brought this insecticide into prominence as a soil fumigant. It is injurious to many plants, and for this reason its use has not been extended to many other insects. To avoid this injury it has been applied in emulsions of both vegetable and mineral oils. Paradichlorobenzene has a limited usefulness as a household fumigant. It is also used when dissolved in kerosene for killing borers in wood products.

Naphthalene

Naphthalene is a white crystalline substance which is sold most frequently in the form of moth balls. It has been used for many years as a household insecticide where it was not always effective. It volatilizes slowly at ordinary temperatures for its boiling point, 424° F., is among the highest of all insecticides used as fumigants. Probably this is a factor in its relative ineffectiveness.

Volatilization by heat was found to make this gas useful in greenhouses in the control of red spider and thrips. One and a half ounces to 1,000 cubic feet of space, heated over a lamp so that the volatilization was slow and even for a period of about six hours was recommended. The duration of the exposure required was overnight. Injury to plants occurs even under electric light. The most favorable temperature was found to be about 70° F. and the most favorable relative humidity about 80 per cent (14).

Naphthalene is also sometimes used in fumigation of potting soil for control of the Japanese beetle, for treatment of corms of gladiolus, for protection against thrips, and for treatment of soil in the field to prevent damage by the carrot rust fly (13).

Sulfur dioxide

Sulfur dioxide is probably the oldest fumigant, and is usually derived by burning sulfur. It is toxic to insects but has many objectionable characteristics. It is corrosive to metals and injurious to grain and flour. Like cyanide it is rapid in action. It still has a limited use as a fumigant in buildings which do not contain materials that can be injured.

Methyl bromide

Methyl bromide is one of the most recently developed fumigants. Its insecticidal properties were first reported in France by Le Goupil in 1932 (7) and it was first used in the United States in 1935. Its toxicity compares favorably with that of hydrocyanic acid gas. Its action is slower than that of cyanide. It is a

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colorless liquid which boils at 40.1° F., the lowest boiling point of any of the fumigants discussed here. The gas is 3.27 times as heavy as air, it is practically non-flammable and very slightly soluble in water (7).

Methyl bromide has been found to have a wide field of usefulness. It is used to fumigate mills, elevators, and storage houses, and in some instances food products and a wide range of living plants. On account of its weight in comparison with air it readily penetrates masses of grain. It can be used at relatively low temperatures. It is highly toxic to insects at low dosages and hence comparatively cheap.

Although it is one of the most effective fumigants in buildings of modern brick or concrete construction and atmospheric vaults, it cannot be used satisfactorily in most buildings because the gas escapes too quickly. On account of its low boiling point the gas is shipped under pressure in steel cylinders. It is dangerous to man and should be handled only by professional fumigators (7, 20).

Cyanide

Hydrocyanic acid is one of the most extensively used fumigants. For the fumigation of buildings there is no gas which is more efficient. Its action is rapid and for this reason is effective in enclosures that cannot hold concentrations of a gas for a long period of time. On account of its high toxicity the dosages necessary are low and consequently relatively less expensive. Its most extensive uses are in fumigating buildings and in fumigating citrus trees under tents.

The development of hydrocyanic acid gas fumigation, particularly on citrus as reviewed by Woglum (30) is largely the basis of the following historical account. Hydrocyanic acid gas fumigation was discovered in 1886 by Coquillet. In its early stages fumigation of citrus was not fully practical. The tents were heavy, bell-shaped, sometimes oiled and almost gas tight. They were very cumbersome, and the labor involved was slow and expensive. Gas was generated by dropping concentrated acid onto dry cyanide; the process was slow and the results were of uncertain uniformity.

By the early 90's, the heavy bell-shaped tents had given way to flat octangonal sheets of relatively light canvas which could be easily handled. The simple pot method of generation, that is dropping the cyanide into dilute acid, had come into use. Day fumigation had been superceded by night fumigation, with the resulting reduction of injury to plants. Marking tents to facilitate exact calculation of dosage was developed by Morrill in 1909. Prior to this time there was confusion among fumigators regarding the desirable dosages, exposure, proportion of chemicals, and the procedure in general.

Potassium cyanide was used almost exclusively as the source of hydrocyanic gas up to 1909. Sodium cyanide was introduced by Woglum and McDonnell, and when the price of potash products rose during the war, the use of sodium cyanide became general. A portable fumigation machine for generating gas outside of tents was developed in 1921 by Dingle. Dingle in California and Mally in South Africa, independently in 1916, developed liquid hydrocyanic acid. Today liquid hydrocyanic acid is the usual source of gas for fumigation of citrus in California. The use of calcium cyanide dust as a source of gas in citrus fumigation was reported by Quale in 1922.

The development of fumigation in relation to citrus is most easily traced. Between 1893 and 1900, cyanide gas was successfully used in treating greenhouses, nursery stock, stored products, mills, and other buildings. Fumigation with hydrocyanic gas under vacuum to make possible penetration of gas into dense material like bales of cotton was developed by Sasscer and Hawkins in 1913.

Methods of Cyanide Fumigation

The "pot method" of generating hydrocyanic acid gas is used in fumigation of mills and large buildings. The gas is usually derived from sodium cyanide, mixed with water and sulfuric acid. Sodium cyanide is a white crystalline substance. It should be handled with a scoop and with gloved hands. Sodium cyanide is also available in the form of cyanagen "eggs" of one ounce each, and in this form it is more convenient to handle and to determine an exact dosage. Sulfuric acid is a heavy colorless liquid which is corrosive and will cause injury if it spatters on the body of the operator or upon the floor. The dosage usually recommended for 1,000 cubic feet of space is one pound of sodium cyanide, 1½ pints of sulfuric acid, and 2 pints of water. This dosage is varied, however, to suit the condition. In mills several stories high, a larger amount of material is used on the lower floors than on the upper. Earthenware jars or barrels make suitable containers for generators. The choice of size of generators depends upon the space to be treated. They should be large enough to prevent acid from "boiling over" on the floor (1). In mixing, the acid is first poured into the water. The cyanide is added last. Elaborate directions for procedure in mill and house fumigation are available and may be referred to by a beginner in cyanide fumigation. The best fumigation temperature is 70° F. or above. Fumigation should continue 12 to 18 hours.

Fumigation by the use of liquid hydrocyanic acid gas is employed in mills and also in tent fumigation on citrus. Liquid hydrocyanic acid is a volatile colorless liquid which boils at 79° F. Upon exposure to air it changes to a gas lighter than air. It is marketed in steel cylinders. It is applied in a tent or building from the outside. For fumigation of mills, special equipment of piping and spray nozzles is required. This is always handled by professional fumigators and will not be discussed here.

In fumigating baled cotton for the control of the pink bollworm, an attempt to overcome the low penetrating power of hydrocyanic acid gas by fumigating in vacuum has been made.

Calcium cyanide is most frequently recommended as the source of gas for house and greenhouse fumigation and is occasionally used in mills or elevators. It is sold in cans either in dust or granular form. Upon exposure to air the powder or granules absorb moisture and liberate hydrocyanic acid gas. The fact that neither the use of acid nor of special equipment is necessary recommends this material to the small operator. When a building is to be fumigated with calcium cyanide, the cans should be distributed about the building where they will be used. The fumigator should begin distributing on the top floor and farthest away from the exit. The dust should be scattered in layers not more than half an inch thick. To facilitate removal of the residue after fumigation it is an advantage to distribute the dust on paper.

Liquid hydrocyanic acid adsorbed in an inert material in the form of waferlike paper discs, known as "discoids", are used in fumigation. These discoids are packed in cans and the manner of handling and distribution in a room is similar to that of calcium cyanide.

Recently calcium cyanide has been used experimentally as a source of hydrocyanic acid gas in fumigating grain in elevators. Granular calcium cyanide is mixed with the stream of grain as it is moved in the elevator, thus overcoming the lack of penetrating quality, which characterizes the gas. Among other advantages claimed for this material over carbon disulfide are that the fire risk is removed and that fumigation may be conducted at a relatively lower temperature.

Fumigation of living plants with cyanide is largely limited to treatment of citrus trees under tents in California, to nursery stock, and to greenhouses. Citrus fumigation is generally handled by professional fumigators and liquid cyanide is generally used. The exact charge for each tree is calculated and liberated in the tent.

In greenhouses calcium cyanide as a source of gas has practically replaced other methods of fumigation. Relative cheapness and the ease with which it may be handled are its chief recommendations. The dosage recommended is one-fourth of an ounce to each 1,000 cubic feet of greenhouse space (29). This is equivalent to one-eighth ounce of sodium cyanide released by acid. In greenhouses cyanide is effective against most insects. Like nicotine it is not effective against mites.

The presence of moisture in the air or on plants increases the liability of injury to plants from the use of hydrocyanic acid gas. This is often a limiting factor in its use. While fumigation is the dominant type of insect control used on citrus in California where the air is relatively dry, it has never progressed in the humid citrus regions of Florida and the Gulf Coast. In these sections contact insecticides are depended upon, since fumigation, at least by the older methods, injures trees. Even in California fumigation must be finished before the rainy season begins. In fumigating greenhouses and nursery stock, moisture must always be considered.

Hydrocyanic acid gas is depended upon largely in house fumigation and in the destruction of rodents. Calcium cyanide is at present the favored source of gas for this purpose. This type of pest control will not be considered here. Calcium cyanide is sometimes recommended as a dust to be used in the field for the control of hardy insects like the harlequin cabbage bug and is used under a canvas trailer for control of the squash bug.

Experimentally calcium cyanide has been given trial in a number of other types of insect control. In South America and India it has been tried with apparent success against a number of species of termites and ants by pumping the dust into their nest chambers. To a limited extent it has been used as a soil fumigant, in open air dusting, and in poison barriers.

Nicotine

Nicotine is used as a greenhouse fumigant particularly for the control of aphids and white flies. For fumigation free nicotine should be used. Usually the nicotine is absorbed in combustible materials and liberated by burning. The chief advantage of nicotine for such use is its relative safety to plants. The gas is lighter than air and is of value only where penetration is not required.

Heat

Heat is sometimes used for insecticidal purposes (10) and is probably more generally useful against stored product insects than any of the materials listed, except carbon disulfide and hydrocyanic acid gas. A temperature of 120° F. to 125° F. for 10 to 12 hours is fatal to most insects (1). The period heat should be maintained in a building depends upon how long it takes for this temperature to penetrate to all parts of the building. As a rule 24 to 48 hours is recommended. The application of heat as a means of control of insects is easier and cheaper in summer than in other times of the year.

Heat has replaced hydrocyanic acid gas to quite an extent in mill fumigation. The chief disadvantage is the cost of installing the equipment necessary. The initial cost is the chief expense, however. Over a period of five years, it is cheaper than fumigation, in addition to being absolutely safe to human life and somewhat more effective than hydrocyanic acid gas. It also kills insect eggs which are not affected by most fumigants. Control by heat of stored product insects on the farm has never been given much attention except by the housewife.

The application of heat to cotton seeds to kill pink bollworms that might infest them is required in some sections of the country where this pest occurs.

Hot water and vapor heat are sometimes used as a means of applying heat to pests on living plants which might be injured by dry heat. The former has been recommended for destroying sugar cane borers in "seed" or joints of cane used for planting and for destroying pests in bulbs. The latter is also employed in treating bulbs and was developed for treating citrus fruits infested with Mediterranean fruit fly larvae.

Low Temperatures

Low temperature may be utilized in insect control. According to Back (1) in mills which are equipped so that they can be exposed to freezing without injury to equipment, insects will be destroyed by exposing the mills to a temperature of zero or below for 3 to 10 nights continuously. Obviously this type of control is useful only where low temperatures occur. During winter grain in elevators may be cooled by transferring it from one bin to another.

Vacuum

Back and Cotton (2) have shown experimentally that the usual household pests may be killed by exposure to a vacuum of 24 to 28 inches. In the experiments the vacuum was maintained for 7 days.

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CHAPTER IX

INSECTS CONTROLLED BY FUMIGATION OR UNFAVORABLE TEMPERATURES

When fumigation is used in insect control it is always necessary to restrict the free dispersal of the gas. For this reason fumigants are most frequently used to control insects attacking products stored in buildings in which the gas can be confined. The use of tents in citrus groves serves the same purpose. When fumigation is used to destroy insects in the soil either the fumigant is covered with earth like paradichlorobenzene before it becomes a gas, or it penetrates the soil in liquid form before volatilizing.

When infested materials to be fumigated must be moved to a place of treatment the insects concerned must be those limited in their activity. The same is true of those insects which are killed by fumigation in the field. As for instance, covering trees with tents is satisfactory for killing scale insects, but is not recommended for destroying actively flying moths.

In this discussion more attention will be given to insects which may be controlled by fumigation or high temperature by the layman than to those which necessitate attention by the professional fumigator.

THE RICE WEEVIL

The rice weevil* sometimes called the black weevil, divides with the Angumois grain moth the rating as the most destructive insect pest of stored grain. Frequently these two insects are responsible for ruining the greater part of grain held late in storage on farms in the South. The rice weevil attacks all of the important cereals. While it is most destructive to grain in storage, infestation is frequently begun on grain in the field in the dough stage. It cannot live on the vegetative parts of any of its hosts nor on grains before they begin to harden.

It has been estimated that 10 per cent of all grain in storage in the South is destroyed by insects. The greatest damage is in spring and early summer when the weevil population is greatest. At this season of the year 50 to 90 per cent of the grain in storage on farms in the South may be destroyed. If more grain should be grown in the South the proportion of damage will be greater.

The adult weevil is somewhat elongate and about a tenth of an inch in length. Its color varies from a reddish brown to nearly black, with two spots on each elytron. The larva, like other weevil larvae, is a stout white footless grub. Feeding injury is caused by both the larva and adult. The egg is deposited in a cavity in the grain made by the adult and the entire immature life is spent within the grain attacked.

The duration of the immature stages from egg to adult is about 28 days in midsummer, although under most favorable conditions it may be shorter. After the adult emerges from its larval cell it feeds for about seven days before it begins to deposit eggs. Thus about 35 days are necessary for a generation from egg to egg. The life of the adult may extend over 100 days and during that period it may deposit about 400 eggs. Oviposition is more rapid in the earlier part of its adult life and gradually declines as the weevil advances in age. Since the oviposition period is so long the generations overlap and no distinct "broods" of weevils occur. Breeding is continuous throughout the year when temperature permits. The short life cycle and high fecundity gives this weevil remarkable possibilities for increase and destructiveness (2, 5).

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*Sitophilus oryzae (L.); family Curculionidae.

There is no true hibernation stage (6). In southern parts of the Gulf States all stages may be found throughout the winter although activity and larval development is very slow at this time. This weevil becomes dormant at 45°F. and cannot survive this temperature when it continues for much over a month. It has been found in Alabama, however, that when winter temperatures do not fall below 20°F. the winter mortality does not exceed 10 per cent (4).

Weevil activity begins in the spring in grain in storage, and sometimes continues throughout the year in the granary or crib. When corn begins to harden in the field it is also subject to infestation. Field infestation is particularly important in early corn. Weevils are frequently brought to grain in storage by grain infested in the field. Late corn is not as likely to be infested as early corn since weevil activity in the field is less late in the season. Corn well protected by husks is less subject to infestation. Dry weather or any factor which dries grain tends to retard the development of the species. Grain with a very low moisture content may cause death of the weevils, not because of hardness but because a deficiency of moisture in the grain causes a breaking down of the fatty tissues of the weevils to supply the moisture (6).

While weevils may continue breeding throughout the year in elevators and warehouses, the concentration of weevils in farm storage is greatest in spring or early summer. Their numbers are finally reduced as the supply of grain in storage is utilized. Weevil population may begin to build up again in the fall if conditions are favorable. Little injury occurs during winter, and when winters are severe infestation may be destroyed by low temperature. Where winter merely retards activity, the infestation in the spring may already be large and on account of the short life cycle rapidly reaches a climax in destructiveness.

Control

While this insect is an important pest on grain in storage the problem of control will be discussed only as it occurs on farms in the South where the important grain crop is corn.

Fumigation of infested grain or exposing weevils to a temperature of 124°F. for two hours has been recommended for control. The heat treatment will kill all stages including eggs. If carbon disulfide is used as a fumigant a dosage of 8 pounds to 1,000 bushels will be effective in an air tight bin with a minimum exposure of 36 hours. As a rule, however, dosages of 20 to 40 pounds or approximately 2 to 4 gallons are recommended, depending upon the tightness of the bin and upon temperature. Fumigation at a temperature below 60°F. is not recommended. Liquid carbon disulfide should be sprinkled evenly over the surface of the grain. If the fire hazard is such that the use of carbon disulfide is not considered advisable, the mixture of ethylene dichloride and carbon tetrachloride, containing three parts of the former to one of the latter, may be used at the rate of 6 to 7 gallons to 1,000 bushels of grain. This mixture should be applied like carbon disulfide. Covering grain which is treated with a fumigant in a partly filled bin with a canvas will help to confine the gas (3, 4).

Seasonal timing of control operations will reduce the difficulties of the problem. It is easiest to break the cycle of reproduction in summer months before corn in the field is nearly mature enough to attract infestation. Fumigation is of most value in the spring when weevil activity and reproduction are resumed. This will check the weevils before they have built up to their greatest numbers and before the peak of destructiveness occurs. If all of the weevils are killed it will prevent infestation of newly harvested grain brought into storage, and will remove one source of infestation of nearby field corn. It has the further advantage that in

spring the amount of corn carried over for feed until the new crop is available is relatively small. On many farms in the South the corn not used by spring is little more than a remnant, and expense of fumigation is accordingly less (4).

Unfortunately the problem is seldom a simple one of dosage, for granaries and open cribs in which most corn is stored are not usually adapted for fumigation or heat treatment. Small bins súitable for fumigation may be available. For successful fumigation a room should be built especially for this purpose. The walls should be of matched lumber with paper between. It is easier to move the grain on hand into the fumigation room in the spring than it would be to move the entire crop in the fall. If the amount of grain on hand is small it can be stored in the fumigation room.

To be fully effective fumigation must be supplemented by sanitation, that is, all grain waste about the cribs or storage rooms should be fed or destroyed. All waste grain should be cleaned from the floors and the bin sprayed thoroughly with a contact insecticide (4). When early corn matures in summer it should not be left in the field to attract infestation. Early maturing corn is more subject to field infestation than late corn since late corn is not mature enough to attract weevils until cool weather begins. Crib infestations are frequently renewed by bringing in early corn for feed. If early corn is infested when harvested it should be fumigated and be handled separately from the late crop (4).

THE PEACH TREE BORER

The peach tree borer* is one of the most injurious pests of the peach tree, wherever peaches are grown east of the Rocky Mountains. It feeds in burrows just under the bark usually just below the soil line. These burrows can be located easily by means of gum and sawdust which exude from them. All ages of trees are attacked. Trees may be killed outright by girdling or may be weakened so that they are susceptible to attack from shothole borers or diseases. As many as 50 borers have been found in a large tree.

The peach tree borer is a yellowish white caterpillar about an inch long when full grown. The adult is a slender steel blue, clearwinged, day flying moth. It has one generation a year. None of its stages have a well defined period of occurrence, however. Moths are on the wing in Arkansas from early May until the middle of October although late emergence is mostly over by the middle of September. A similar period of emergence of the moth occurs in southern Illinois, although it begins a little later and the peak of emergence is concentrated in late August and early September (10).

The incubation period may be as short as five days in midsummer. The larval feeding period is a little less than a year. The minimum period in the cocoon is about 18 days. The oviposition period is about six days. Moths are active during the heat of the day. The eggs may be deposited anywhere on the peach tree or even on weeds on the ground around it. However, according to Becker (8) about 85 per cent of the eggs are deposited in crevices of the bark around the base of the tree. A single moth may deposit as many as one thousand eggs.

Control

Destroying the borers by digging them out by hand once or twice a year was formerly recommended for control. Between 1916 and 1919 fumigation of the soil about the base of the tree with paradichlorobenzene was developed (9) and this has largely replaced "worming". In making an application the loose soil is scraped away from the base of the tree. A band of the fumigant about an inch wide and about an inch

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*Sanninoidea exitiosa (Say); family Aegeriidae.

[illegible] the amount of corn carried over for feed until the new crop is available is relatively small. On many farms in the South the corn [illegible] used by [illegible] is [illegible] [illegible] a [illegible], and [illegible] of the [illegible] is [illegible] (5).

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To be fully effective fumigation must be supplemented by [illegible], [illegible] waste about the [illegible] or storage rooms should be [illegible]. [illegible] should be cleaned from the floors and the bin sprayed thoroughly with a [illegible] (5). When seed corn [illegible] it should not be left in the field [illegible]. [illegible] weather [illegible]. [illegible] by [illegible] corn for feed. [illegible] it should be [illegible] and be handled separately [illegible] (5).

The Peach Tree Borer

The peach tree borer is one of the most [illegible] pests of the peach tree. [illegible] peaches are grown east of the Rocky Mountains, [illegible] usually just below the soil line. [illegible] by masses of gum and [illegible]. All ages of trees [illegible]. Trees [illegible] susceptible to attack [illegible] (5) [illegible] trees.

The [illegible] is a [illegible] inch long when [illegible]. [illegible] moths. [illegible] 2 [illegible]. [illegible] have a well defined period of [illegible]. [illegible] are on the wing [illegible] from early May until [illegible] late [illegible] September. A [illegible] in southern Illinois, although [illegible] late August [illegible] (10).

The incubation period [illegible]. The larval [illegible] period is [illegible] year. The minimum period in the record is [illegible] 8 days. [illegible]. Moths are active during [illegible] of the day. [illegible] on the peach tree or even [illegible] on the ground [illegible]. [illegible], according to [illegible] (9) about [illegible] of the eggs are deposited [illegible] the bark around the base of the tree. [illegible] may [illegible].

Control

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*[illegible]

from the base of the tree is distributed around it. A mound of earth is then built up around the base of the tree to prevent too free diffusion of gas. The gas is effective for a period of about three weeks and will destroy larvae at a depth of 8 to 12 inches and from 6 to 8 inches away from the trunk laterally. The dosage recommended is one ounce to trees six years old or older. Very large trees, 12 to 18 years old, may require one and one-fourth to two ounces. Younger trees are more susceptible to injury and for this reason the dosage is reduced to three-fourths of an ounce for three,four and five years old and one-fourth to one-half ounces for trees one to three years old.

Injury to peach trees is sometimes caused by paradichlorobenzene which has been described as killing small spots of tissue under the bark or even girdling the tree. Such injury may be of more importance in the Georgia peach belts than farther north. In Illinois where attention has been given to this for many years Chandler (10) has neither observed nor heard of any serious loss in commercial orchards where the insecticide has been correctly applied. He states that one-year old trees can be treated with comparative safety. On the other hand, nursery stock should never be treated with paradichlorobenzene crystals.

To reduce the possibility of injury, emulsions including paradichlorobenzene and ethylene dichloride have been developed (11, 12). The ethylene dichloride emulsion appears to have the greatest possibility of usefulness. It has an advantage over paradichlorobenzene crystals in that the danger of cambium injury to peach trees is so much less that it may be applied even to nursery stock, and also that it is more effective at low temperatures. Its disadvantage is that the emulsion must be applied either by pouring around the trees or by spraying the base of the trunks. The former is simpler but involves more labor; the latter requires the use of a special device at the end of the hose for regulating the amount of liquid used on each tree. The cost of operating the sprayer adds to the expenses, although this is largely offset by speed of operation (10).

The dosage of ethylene dichloride emulsion recommended is one-half pint of 20 per cent emulsion for trees six years old or older, and one-eighth pint of seven and one-half per cent emulsion for nursery stock (12).

The time of application is preferably about two to three weeks before the last hatching at the end of the season. At this time the soil temperatures are high enough to produce complete volatilization of the gas, and the chance of reinfestation that season is relatively small. Thus practically complete eradication can be secured. In the latitude of Washington, D. C., this is about September 10; in northwestern Arkansas, September 25; in Georgia, October 10 (9). In experiments widely scattered over the United States, in Virginia, West Virginia, Georgia, Maryland, Ohio, and Arkansas, carried on by Blakeslee, about 94 per cent of the borers were killed (9).

THE JAPANESE BEETLE

The Japanese beetle*, a pest of Oriental origin, occurs in the United States in a large area in the states of New Jersey, Pennsylvania, Delaware, New York, Maryland, Virginia, West Virginia, and Ohio, with scattered infestations in the New England States, Michigan, South Carolina, and Missouri. Within the area of continuous infestation the adult is a pest of first rate importance on small fruits, tree fruits, many shade trees and ornamentals, and many herbaceous crops. The larva is also of importance, as it feeds upon grass roots. The economic loss felt by this region

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*_Popillia_ _japonica_ Newn.; family, Scarabaeidae.

cannot be covered by crop losses only, but is increased by quarantines, which prevent or restrict shipment of various agricultural products out of this region. The beetle was first found in the United States near Riverton, New Jersey, in 1916. Within four years it became so abundant that 15 to 20 thousand could be collected by a single individual by hand in one day.

The Japanese beetle is of interest to that part of the United States outside of its present range as a possible future pest, for the infested territory will undoubtedly increase. It is of especial interest to the student of applied entomology because of the intensive study of methods of insect control which have been prosecuted on its account. For this reason it serves to illustrate the advantages in the use of different fumigants and high temperatures under varying conditions. Many of the control practices are too expensive for general agricultural utility, but may be useful in intensive plant production. Since the study has been so extensive no attempt will be made to present a complete outline of all the fumigation practices which may be followed.

The Japanese beetle resembles other Scarabaeid beetles in general structure. It is about half an inch long, broadly oval and shining metallic green in color. The wing covers are a coppery brown. The other destructive stage, the larva, is a small white grub which when full grown is about an inch in length.

The hosts of the adult Japanese beetle are widely distributed among the dicotelydenous plants. Almost all tree and bush fruits within its range are subject to attack. Not only may the trees be defoliated but the fruit which ripens when beetles are abundant is subject to attack and at this time is very difficult to protect. This includes early peaches, early apples, plums, cherries, raspberries, and blue berries. Isolated shade trees may be attacked while the same species in forests are not injured. The injury to foliage is first at the top and on the outside of the tree. Among the herbaceous crops severely injured are beans, beets, okra, red clover, and soybeans. The smartweed is a preferred herbaceous host (17).

The larvae feed on the roots of grasses and of field, garden, and nursery crops. Fine-rooted grasses, or grasslands which are frequently clipped, are preferred. As many as over 1500 larvae have been found in a single square yard of turf on a golf green. One hundred to a square yard will kill sod, at least in periods of deficient rainfall. This beetle is not a serious pest in Japan. In part this is said to be due to the very small percentage of grassland in Japan available for larval food.

The life history, seasonal history, and habits in New Jersey (17) may be summarized as follows: There is one generation a year in New Jersey. (In northern Japan there is one generation every two years, indicating that the number of generations is in a sense a response to climate. If the species becomes established in the states along the Canadian border it is probable that two years will be required for a generation.) It winters as a third stage larva in the soil below the frost line. When the soil becomes warm in May, the larva moves up near the surface and feeds upon roots. Upon becoming full grown it forms a pupal cell. The prepupal period requires 5 to 7 days and the pupal 9 to 12 days. The adult remains in the pupal cell for 3 to 4 days until it has hardened. It then comes above the ground and feeds upon low-growing plants like smartweed. In about 10 days it moves to deciduous trees. The adult becomes sexually mature in 5 to 7 days after emergence from soil. Females return to the soil late in the afternoon and deposit eggs at a depth of about two inches. They return to trees during the morning. The maximum number of beetles are on the trees about two p. m.

Emergence of adults from the soil in New Jersey begins the last of May and continues until mid-July. They begin to leave fruit trees about the middle of August and return to low-growing vegetation. The last beetles are active in October.

After eggs are deposited in the soil, they hatch in about 11 days. The larvae feed in the soil, passing two molts, and with the approach of cold weather go down below the frost line for hibernation. Heaviest injury by larvae occurs in late fall and in the spring. Soil temperature is an important factor in the rate of development.

The beetles spread by flight for short distances from centers of infestation. They may also be transported for longer distances among fruits, vegetables, and cut flowers in which they may hide. The danger of distribution of beetles by this means is limited to the season of adult occurrence. The larvae may be distributed in the soil or among the roots of nursery stock and potted plants. Most of the danger of distribution of larvae is during the dormant season.

The Japanese beetle is affected adversely by drought. If the summer rainfall amounts to less than 10 inches many of the eggs and small larvae perish. During dry summers the beetles have a tendency to deposit eggs in low, wet places rather than to deposit them evenly over the field. From a study of the weather records it is believed that the beetle will be able to develop in most of the United States east of western Kansas.

Control

Control measures are directed against both adults and larvae, not only to protect the plants which they attack but to prevent their distribution. In addition, parasites of the Japanese beetle have been imported from the Orient. Control by fumigation and heat will be considered in this discussion*, and control by spraying in Chapter XIII.

The Japanese beetle larvae may be distributed in the soil around plants. For this reason when plants are potted for shipment the soil used must be free from infestation. This should also be true of soil in which plants are heeled in or plunging soil in which potted plants are placed temporarily. To destroy larvae in soil which may be used for potting plants one of three methods may be employed, the choice of which will probably be determined by the equipment available. The infestation may be destroyed by heating soil to 130°F. and maintaining this temperature for 30 minutes. This requires special equipment which usually is hot water pipes. If a tight bin or box is available the soil may be fumigated with carbon disulfide at the rate of one pound to one cubic yard. Naphthelene may be mixed with soil at the rate of five pounds to one cubic yard and left undisturbed for a week. Soil in and around cold frames, plunging beds, heeling in areas where plants for shipment will be placed temporarily may be freed from infestation by using heat from hot water pipes or by using the same insecticides. The requirements are necessarily different for the fumigants. Carbon disulfide should be used at the rate of six pounds to 100 square feet and the surface must be covered with heavy paper or some other gas proof material during the period of fumigation. Naphthelene should be applied at the rate of 46 pounds to 1000 square feet and incorporated in the upper three inches of the surface (14, 15, 20).

Infestation about roots of plants themselves may be destroyed by heat or by fumigants. If heat is used complete immersion of the roots in a hot water tank is recommended. The equipment necessary is a tank with a controlled heating and circulating system in which an exact temperature can be maintained. The root masses are immersed and a temperature of 112° F. ± 0.5° must be maintained for 70 minutes (20). Potted plants or plants with small balls of earth about their roots may be treated with paradichlorobenzene. The insecticide is mixed with soil which is then spread on a floor or table. Rows of plants are placed on this layer of soil with the balls at least one inch apart. The spaces between the plants are then filled

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*For more complete information see original sources under "Literature".

with treated soil; a layer about an inch deep is placed over the plant balls and against the sides of the rows. If the balls are less than six inches in diameter, the insecticide is mixed with the soil at the rate of ten pounds to one cubic yard; if the balls are six to eight inches in diameter the rate should be 20 pounds to one cubic yard. After treatment the soil should not be disturbed for five days. The roots of plants may be submerged in tanks containing carbon disulfide emulsion, 45 cu. c.m. of carbon disulfide in a gallon, for a period of 24 hours. Carbon disulfide emulsion may be used also for treatment of soil about plants before digging or for treatment of soil itself which is to be used for planting. In either case the emulsion is poured in a metal collar, 10 inches wide. The dosage is varied depending on the temperature of the soil six inches below the surface. Larvae around the roots of plants may be destroyed by fumigation with methyl bromide. Such treatment must be in a fumigating chamber. The required period of treatment and dosage at various temperatures is shown in table 2. (20, 21)

Table 2. Control of Japanese beetle with methyl bromide showing required dosage and period of treatment at stated temperatures. For plants with bare roots, in pots or soil balls not thicker than 12 inches [Copied from B. E. and P. Q. S. R. A. 144, p. 68 (21).]

Temperature at least	Period of treatment	Dosage (methyl bromide to 1000 cu. ft.)
	Hours	Pounds
70°F	$2\frac{1}{2}$	2
63°F	$2\frac{1}{2}$	$2\frac{1}{2}$
54°F	4	$2\frac{1}{2}$
50°F	$4\frac{1}{2}$	$2\frac{1}{2}$

Vegetables and fruits which are moved during the period of adult activity must be fumigated to destroy the beetles. The effect of the insecticidal treat on the products themselves varies with the variety and condition at the time of treatment, and this may determine the choice of the fumigant used. Either carbon disulfide or ethylene oxide may be used in an approved fumigation chamber, the former at ten pounds and the latter at two pounds to 1000 cubic feet and for an exposure of two hours. The required temperature for the specified conditions given is not less than 80° F. when carbon disulfide is used and not less than 75° F. when ethylene oxide is used. Methyl bromide may also be used to destroy infestation with fruits and vegetables in refrigerator cars, at dosages similar to those required for treatment of roots of plants (18, 21).

For the protection of roots of plants during the growing season when these plants are intended for shipment, carbon disulfide emulsion may be used. The preparation of this emulsion has been referred to in the previous lecture. For lawn treatment it should be diluted with water at the rate of 1 to 200. It may be applied with a large nozzle or sprinkling can at the rate of one quart of dilute mixture to one square foot. The mixture should be applied in two coatings, the second being put on as soon as the first has entered the soil. Surface burning of grass sometimes occurs, and injury is more likely to follow in hot weather. The cost of treating an acre of turf with carbon disulfide emulsion in 1925 was estimated at about $110 an acre. The field of usefulness of this emulsion is limited because of its cost. Its use may be justified on lawns and golf courses where the investment in keeping the turf in first class condition is very great (18). Treating soil with arsenate of lead (which will be discussed in Chapter XIII) has replaced the use of carbon disulfide emulsion in many situations.

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SUMMARY

Control of the rice weevil in grain stored on the farm is a problem usually because storage bins which will confine the fumigant are not available. Fumigation may be so timed that it will destroy the infestation before it reaches destructive proportions and when the quantity of grain in storage is relatively small thus reducing the size of fumigation bins needed. Choosing a satisfactory fumigant is less of a problem but the fire hazard involved must be considered.

For control of the peach tree borer the fumigant must be able to penetrate the soil around the crown of the tree and must be used at a rate which will not injure the tree. The seasonal history of the insect should determine the best time for making the application.

Fumigation or high temperature is used to destroy infestations of the Japanese beetle around the roots of nursery and greenhouse plants, and among fruit and vegetables to make transportation of these products out of the quarantined zones permissible. The method chosen may be determined by the facilities available and the resistance to injury of the product to be protected.

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CHAPTER X

STOMACH POISONS

Stomach poisons enter the bodies of insects through their mouthparts, instead of through their respiratory apparatus or epidermis, as is the rule with contact insecticides. For this reason stomach poisons are usually employed in the control of insects with biting mouthparts. Sometimes they are also used in the control of insects with rasping or lapping mouthparts. Most stomach poisons have an advantage over other insecticides in that they are effective over a period of time and not just at the moment of application. For this reason they may be applied when the insects to be controlled are not in evidence, and such applications may have the characteristics of prevention rather than merely of suppression of outbreaks. The timing of applications of stomach poisons, if made when the insects are not in evidence, tends to follow closely seasonal history and life history of the pests to be controlled.

ARSENICALS

The most important stomach poisons contain arsenic as their active element. Among the arsenicals which are, have been, or may be of importance are: Paris green, London purple, sodium arsenite, white arsenic, lead arsenate, calcium arsenate, zinc arsenite, and magnesium arsenate.

Paris Green

Paris green was the first arsenical to come into common use as an insecticide. It began to be used sometime between 1860 and 1870 as a means of control for the Colorado potato beetle which was then crossing the continent. This use seemed well known by 1868, and it was applied as a dust mixed with flour, wood ashes, or lime. In 1872 it was recommended for use against the cotton leaf worm by Riley. The same year LaBaron recommended the application of "strong washes, such as Paris green water or suds made from the whale-oil soap, thrown upon trees with a garden syringe" to control canker worms. Here we have the first spraying recommendation. In 1878 it was accidentally found that trees sprayed with Paris green to control canker worms were also relatively free from the codling moth. Paris green was the most important arsenical for the decade following 1880. It has since been largely superceded by others.

Paris green is still useful when quick killing action is especially desired. Its chief disadvantages are that it is apt to burn foliage, and that it does not adhere well to foliage whether applied as a dust or as a spray. It is now used largely in baits, or for spraying on plants very resistant to arsenical burning, such as potatoes, or in emergencies for such insects as the cotton leaf worm.

Paris green is a copper aceto-arsenite. When pure it contains 58.65 per cent arsenious oxide. By law, Paris green sold must contain not less than 50 per cent arsenious oxide, nor more than three per cent water-soluble arsenic.

London Purple

London Purple is a by-product in the manufacture of aniline dyes, and was once a rival of Paris green. It contains less arsenic and hence is not so effective, and on the other hand it is more injurious to foliage. Its recommendation seems to have been cheapness. It is now hardly ever used as an insecticide except in emergencies like cotton leaf worm outbreaks, when the supply of other arsenicals is short.

White Arsenic

White arsenic or arsenic trioxide is a heavy white powder, which is somewhat soluble in water and very injurious to plant life. It cannot be used as an insecticide against plant feeding insects, except in a bait. It is used as a contact insecticide in the control of cattle ticks. It is of most importance as a source of the other arsenicals.

Sodium Arsenite

Sodium arsenite is the most soluble of the arsenicals used as insecticides. On account of this solubility it is used in bait where a quick acting insecticide is desirable. It is the insecticide most used in bait for grasshopper control. It is so injurious to plants that it is sometimes used as a weed killer, and for this reason has no place in spray mixtures. It is caustic and disagreeable to handle, and should always be used with caution.

Lead Arsenate

Lead arsenate is at present the most important arsenical insecticide. It has been estimated that in 1934 about 20,000 tons were used in the United States. It was first used as an insecticide in a paste form for control of the gypsy moth in New England on foliage which was injured by Paris green. In 1908 the powdered form was developed as an insecticide to be used against the boll weevil. Powdered lead arsenate did not come into general use until about six years later.

Lead arsenate has been the standard orchard insecticide for many years. It is usually used in liquid spray mixtures. Its importance seems to rest on the relative safety with which it may be used on the foliage of most plants, and the fact that in spite of its relatively low arsenical content, it is the most effective insecticide against such insects as the codling moth.

Lead arsenate is used more extensively in control of the codling moth than in the control of any other insect. The results in codling moth control are sometimes unsatisfactory when severe outbreaks occur. For this reason, and because arsenical residue on the fruit may destroy its marketability, a very comprehensive search for a substitute or improvement on this insecticide has been made. This search for a successor to lead arsenate has been carried on by the United States Department of Agriculture and by most of the entomologists at State Experiment Stations in apple producing states. Thus far no wholly satisfactory substitute has been found.

It is not possible to fully explain the effectiveness of lead arsenate in comparison with other poisons which carry much higher amounts of metallic arsenic. Lead arsenate is more adhesive than any of the other arsenicals and for this reason probably withstands weathering between spray applications better. It has also been found that lead arsenate is relatively more effective in controlling insects whose digestive tracts have acid reactions than those having alkaline reactions (2).

Excessive arsenical residue on fruit may prevent its being marketable. Under a ruling by the Federal Security Agency fruit and vegetables carrying more than .025 grains of arsenic to each pound of fruit or vegetable may not be sold in interstate commerce. Furthermore .05 grains of lead per pound is also the limit of tolerance. These tolerances were formerly lower but have been changed to their present status following an intensive investigation of the effect of lead arsenate by the United States Public Health Service (1). The problem of excessive arsenical and lead residue on fruit is partially solved in that this residue may be removed by washing in hydrochloric acid. This may be considered as a part of the codling moth problem and will be discussed later.

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Lead arsenate sold in interstate commerce usually contains not less than 30 per cent arsenic oxide nor more than one-half per cent water soluble arsenic.

Basic Lead Arsenate

Basic or triplumbic lead arsenate was brought on the market as poison to eliminate the danger of arsenical burning on foliage of plants particularly susceptible to injury such as the foliage of the peach tree and the Japanese plums. Of all the arsenicals, it can be used with greatest safety. Unfortunately its toxicity is low and hence it has never come into general use.

Calcium Arsenate

Calcium arsenate was developed about 1914 as a cheap insecticide to replace lead arsenate on fruit trees (4). For this purpose it was not successful, since it caused more injury to foliage than lead arsenate, and it did not give effective control of the codling moth. For a few years it received little attention as an insecticide. It came into importance, however, in the control of the cotton boll weevil and during some years the amount manufactured was nearly as great as that of lead arsenate. On account of the lead residue problem, it has also again received attention as an orchard spray material, and changes were made in its method of manufacture.

Calcium arsenate is usually applied as a dust and not as a spray. For this reason lightness of the material is an essential characteristic. It is also the cheapest of the arsenical insecticides.

Calcium arsenate to be sold in interstate commerce is required by law to contain not less than 40 per cent arsenic oxide and not more than 3/4 per cent water soluble arsenic. The density should be not less than 80 nor more than 100 cubic inches to each pound.

Magnesium Arsenate

Magnesium arsenate recently came to have an insecticidal use as a poison for the Mexican bean beetle. It is the only arsenical, except basic lead arsenate, and sometimes calcium arsenate, which can be used with reasonable safety on beans in the southeastern part of the United States. Its manufacture has been limited because of the low demand. It contains about the same amount of arsenic oxide as lead arsenate.

Zinc Arsenite

Zinc arsenite was introduced on the market as an insecticide about 1912. The powdered form contains about 40 per cent arsenous oxide. In common with other arsenites, it is a very active poison but cannot be used on plants with safety, except those like potatoes which are very resistant to arsenical injury. It is said to be the leading poison used on potatoes in some sections.

NON-ARSENICAL STOMACH POISONS

Sodium Fluoride

This insecticide was first developed as a poison for cochroaches and has since come into prominence in the control of biting lice. It cannot be used on plants because of its high solubility.

Sodium Fluosilicate

Sodium fluosilicate ($NaSiF_6$) was developed by Marcovitch as an insecticide for control of the Mexican bean beetle, and was reported by him as being useful against other insects also. This material is a by-product in the manufacture of acid phosphate. Its usefulness, particularly against beetles, is explained by Marcovitch as due to its irritating effect when it comes in contact with their legs or antennae and as a result the beetles attempt to clean their feet in their mouth. This material is less soluble than sodium fluoride and hence may be used with relative safety on plants. Sodium fluosilicate is applied as a dust, either alone or with an inert carrier which serves as a diluent.

In spite of its advantages, sodium fluosilicate has not come into general use. When handled carelessly it has a tendency to burn foliage, or may kill the plants treated. Nevertheless, it is one of the most useful insecticides against certain leaf beetles, and blister beetles. Usually it should be used with a diluent, preferably talc or some similar inert material. It is also used in baits for snout beetles.

Barium Fluosilicate

Barium fluosilicate has been developed in the search for a fluosilicate which could be used with more safety on plants than sodium fluosilicate. It is now sold in a compound with a carrier and seems to be more satisfactory in the hands of a careless operator. It is somewhat more expensive than sodium fluosilicate. It is applied only as a dust.

Cryolite

Cryolite, sodium fluoaluminate, is the flourine insecticide which will probably cause least injury on plants. It is the only one which can be used in liquid spray and so far the recommendations of this use are limited to the arid regions in the Pacific Northwest. There it may be used under some conditions as a substitute for lead arsenate in two or three spray applications to reduce the load of arsenical residue. A tolerance of fluorine residue has been set not to exceed .02 grains per pound of fruit.

Antimony

Compounds of antimony have been given experimental trial within the past decade for control of certain species of thrips and for use in sweetened sprays or baits for control of certain moths. Tartar emetic is the compound most frequently used.

Hellebore

Powdered hellebore is made from the dried roots of the hellebore plant. It is a weak insecticide whose chief basis for use is that after exposure to air, its poisonous qualities are temporary. For this reason hellebore may be applied on ripening fruits just before harvest. For control of the currant worm about three pounds of fresh hellebore are required to produce the effect secured by using one pound of lead arsenate. In comparison with arsenicals it is expensive.

Rotenone

In an effort to avoid objectionable spray residue the possibilities of organic poisons has been the subject of much investigation. Rotenone, which has been discussed as a contact insecticide, is also of value as a stomach poison. Even the

temporary character of its poisonous qualities is an advantage under some conditions, as is the case with hellebore. For this reason rotenone is filling an important place for use on truck crops, particularly vegetables whose foliage is used for food. As for instance it is recommended for the control of cabbage worms, particularly on cauliflower and broccoli. In addition to being effective for only a short time it has the further limitation of being poisonous only against some species, and general conclusions regarding its effectiveness cannot be made. This specific variability characterizes a number of other organic poisons but does not prevent their usefulness against certain pests.

Fixed Nicotine

An effort to produce a "fixed" nicotine that would have value as a stomach poison and to replace lead arsenate in codling moth control has received much attention in experimental work. Fixed nicotines are now used to a limited extent for this purpose. Those most frequently used are combinations of nicotine in a white oil, and nicotine fixed in bentonite and soybean oil. Fixed nicotine has a disadvantage in summer spraying on apples in that it cannot be satisfactorily combined with fungicides, because the lime contained in those in common use frees the nicotine and destroys its permanence. At best their period of effectiveness is much shorter than that of lead arsenate. The cost is relatively high.

Synthetic Organic Insecticides

Synthetic insecticides which are organic compounds have recently appeared in the experimental field as stomach poisons for control of the codling moth. Among these are phenothiazine and xanthone. The extent of their usefulness remains to be established but nevertheless their occurrence indicates a possible trend in insecticidal development.

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CHAPTER XI

CATERPILLAR AND SAWFLY LEAFEATERS

The majority of larvae belonging to the great order Lepidoptera feed upon foliage. More of the insects which are very destructive to foliage are in this order than in any other. Most of the larvae of sawflies in the Hymenopterous superfamily Tenthredinoidea are similar in habit. The adults are not destructive. Their function is reproduction and distribution of the species, not food consumption. For this reason the adults scarcely enter into the problem of control. The control of leaf feeding larvae is one of the simplest types of insect problems, provided the unit value of the plants attacked is great enough to justify direct measures. It is possible to protect foliage from injury by leaf eating larvae by covering it with a poison which will adhere to it through the period of danger. No effort need be made to hit the insect as is necessary with contact insecticides, nor is the problem of timing particularly difficult since usually it is not necessary to apply the insecticide until injury is threatened. However, the problem varies in many ways. The most important causes of variation are: the susceptibility of the larvae in question to poison; the problem of adhesion on various types of foliage; the question of adequate coverage of foliage; the stage of development of the plant when protection is needed; the frequency and extent of outbreaks; and the problem of poisonous residues on plants used for food.

The insecticide used in spraying fruit and truck crops for the control of surface feeding caterpillars and sawfly larvae is most frequently arsenate of lead. It adheres to foliage well and is relatively safe to use on a great range of plants. The use of arsenate of lead is recommended at dosages varying from one pound to 50 gallons, for such leaf eating larvae as the currant worm, to two and a half pounds to 50 gallons for the gypsy moth. The foliage of some plants such as peaches, pecans, and beans is very susceptible to burning, even by arsenate of lead, and is injured sometimes by minimum dosages. On the other hand, the foliage of grapes and potatoes is very resistant to arsenical burning. For spraying leafy vegetables or plants with ripening fruit on which a metallic residue might be objectionable, rotenone is sometimes used as a substitute for arsenate of lead. Other arsenicals and cryolite are sometimes used in control of leaf feeding larvae.

The dosage of poison required to kill an insect is exceedingly variable. As a rule those insects which feed most voraciously and grow most rapidly are easiest to kill. The currant worm* is an excellent example of this. Under favorable conditions the currant worm will pass its five or six molts and complete its growth in 10 to 12 days. The suddenness with which currant worms will strip a field of currants or gooseberries after the infestation is first noticed is frequently astonishing to the grower. However, they are easily killed. The writer has used arsenate of lead in dosages as low as half a pound of 50 gallons of water and secured perfect control. The only problem in currant worm oontrol is knowing when to expect it and being ready to apply poison when necessary.

Many leaf eating insects are controlled incidentally by measures directed against other insects. As for instance, there is a long list of caterpillars which attack the apple foliage from the time the buds begin to show green until near the end of the season. These caterpillars are almost never of importance in bearing orchards because the succession of sprays which are applied to control the codling moth also controls the leaf eaters. Nevertheless, they do cause damage on young trees which do not receive the regular spray applications, and also in unsprayed orchards.

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*Pteronidea ribesii (Scop.); family Tenthredinidae.

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Some species are very easy to control. As for instance, the yellow-necked caterpillar* occasionally defoliates unsprayed apple trees in midsummer. These caterpillars can be killed by a spray containing as little poison as one pound of arsenate of lead in 50 gallons of water. Since they are gregarious, their feeding is conspicuous and easy to locate. Spraying operations can be timed by the presence of the caterpillars and does not depend on any accurate knowledge of life history or seasonal history. Since at the time of their occurrence the growth of foliage is slight, a single spray application will keep the surface covered for a relatively long period.

The canker worms** which may also strip apple foliage present a different problem. These insects have but one generation a year. Canker worms hatch early in the spring and may appear on the buds when they first show green. When they are very numerous they may not only defoliate apple trees but may destroy the flower buds before they open. Such damage almost never occurs in commercial orchards but is a problem of the home orchard. The canker worm is harder to control than the yellow-necked apple caterpillar because it occurs only in the spring of the year when the foliage is expanding rapidly. Also the large canker worms may be more resistant to arsenical poison.

THE IMPORTED CABBAGE WORM

The imported cabbage worm*** is one of the best known garden insects and sometimes is regarded as the worst pest of cabbage. The larva is a velvety green caterpillar, the adult a white butterfly. The larva feeds upon the foliage of most of the cultivated cruciferous plants including cabbage, cauliflower, broccoli, mustard, turnips, and rape, and upon many of the wild crucifers also. The leaf tissue of young plants except the midribs may be entirely consumed, resulting in a ragged appearance of many of its hosts. Cabbage with heads formed may be riddled by larval feeding. This insect is a native of Europe which became established in America during the last half of the nineteenth century.

The imported cabbage worm passes winter in the pupal stage. The butterflies emerge in early spring and deposit eggs on whatever food plants are available. The eggs hatch in four to ten days. The larvae are voracious feeders and may become full grown in as short a period as ten days. During the midsummer the whole life cycle may be passed in about three weeks. The number of generations depends upon the length of the season. In the northern states there may be three generations a year while in the southern states there may be twice as many. In the extreme South butterflies remain on wing all winter (1).

The cabbage worm is easily killed by stomach poisons. Nevertheless the problem of control is removed from the most simple type by the following factors: The foliage of cabbage is waxy and for this reason an aqueous spray solution will not adhere readily to it. The foliage of many of its hosts are used for food and must not bear an excessive amount of spray residue when offered for sale. The rapid growth and destructiveness of the caterpillars makes prompt action necessary when they first appear, while the large number of generations results in an intermittent threat of damage throughout the season wherever cruciferous crops are grown.

The caterpillars are easily killed by a spray using two pounds of arsenate of lead to 50 gallons of water or by an arsenical dust. If a spray is used resin soap

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*Datana ministra Drury; family Notodontidae

**Paleacrita vernata (Peck), and Alsophila pometaria (Harr.); family Geometridae.

***Ascia rapae (L).; family Pieridae

or one of the colloidal spreaders should be used to insure adhesion to the waxy foliage. It is not advisable to apply an arsenical on leafy vegetables which are used for food, however, unless the leaves which are sprayed can be removed before using. This treatment of cabbage is sometimes regarded as safe, because the growth of the head is from within and the leaves bearing poison can be removed when the crop is harvested. Dusting cabbage within 30 days before harvest is likely to leave an excessive insecticidal residue (3). To avoid all possibility of such residue, applying a dust containing .5 per cent of rotenone has been recommended (2, 4). This is particularly important on cauliflower, broccoli, brussels sprouts, and loose heading cabbages from which the leaves bearing spray residue cannot be removed. It has been found that two applications of 25 to 30 pounds of dust to the acre has adequately protected cauliflowers in New York (2). Arsenicals may be applied on small plants, but retenone bearing insecticides should be used as harvest approaches. The time of making applications is variable and should be determined by the occurrence of feeding injury. In New York, where only three generations occur, a succession of applications to destroy second generation larvae has been found of value in preventing damage near harvest by the third generation and thus the residue problem is avoided (3).

THE PECAN LEAF CASE-BEARER

The pecan leaf case-bearer* is one of the worst pests affecting the culture of pecans in orchards in the southern portion of the pecan-growing area. The pecan is its favored host, although it feeds upon other hickories and the Japanese walnut. It occurs over the range of its favored host.

The most serious damage by the pecan leaf case-bearer is done during the early spring and is inflicted by the worms which emerge from their winter cases and feed voraciously upon the unfolding buds and leaves. These worms, or larvae, are small at this time and dark brown, but soon change to dark green as they feed upon the foliage. On badly infested trees the buds and tender leaves suffer serious injury, and often the foliage is consumed by the larvae as fast as it is put forth. According to Gill (6), it is not unusual to see pecan trees kept in a defoliated condition for weeks during the spring on account of the attacks of this insect. Since the larvae devour the blossom buds as well as the leaf buds, they may reduce the yield of nuts for the current season, and also leave the trees in a more or less weakened condition.

Only one generation of the pecan leaf case-bearer develops during a year, and more or less variation exists in the time of occurrence of the different stages. The moths reach maturity from late spring to near midsummer over a period of nearly three months. Because of the wide variation in emergence of moths, a corresponding variation occurs also in the time of egg laying. Eggs are deposited always on the under side of the leaves and usually near the junction of the vein with the midrib. The egg stage varies from 6 to 9 days. The eggs hatch from late spring to midsummer. The young larvae commence feeding upon the leaflets immediately adjacent to the place where eggs were deposited and as they feed they begin building their protective cases. Throughout the remainder of summer and during the early fall the larvae feed sparingly. Shortly before the foliage begins to drop in the autumn the larvae abandon the leaves upon which they have fed and attach themselves securely to the buds and twigs where they construct oval silken cases known as hibernacula. They remain in hibernation until spring when the buds on pecan trees begin to open.

As the buds are opening, the larvae emerge from their winter cases and attack the unfolding leaves. They feed voraciously during the spring and some of them

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*Acrobasis juglandis (LeB.)

reach full growth within a month after leaving hibernation, but the majority do not attain full growth until early summer. The larvae always transform to pupae within their cases where the pupae later transform to the adult stage.

Spraying when the buds are swelling, which is the time when the pecan leaf case-bearer causes its greatest damage, is of little value because the daily increase in leaf size rapidly reduces the proportion of the surface covered with a protective spray. In late summer, however, when there is little leaf growth it can be easily controlled by a single application of lead arsenate or calcium arsenate. The insecticide should be used at the rate of one pound to each 50 gallons of 3-4-50 Bordeaux mixture (7). Since pecans are so susceptible to arsenical "burning" the insecticide should not be used in humid regions without a Bordeaux mixture or lime as a corrective as a more or less serious injury to the foliage or nuts is likely to result. In regions where humidity is low this danger does not occur for Bilsing has used three pounds of arsenate of lead to 50 gallons of water on pecans without foliage injury (5). Spraying should be done in the period between the hatching of the last eggs and before the oldest larvae stop feeding to form their hibernacula. The problems involved include avoiding spray injury on the susceptible pecan foliage, the height of trees, and timing the application.

THE COTTON LEAF WORM

The cotton leaf worm* is one of the easiest of insects to control. The worms can be killed by arsenical poisons, and problems of adhesion, injury to foliage and residue scarcely need be considered. Nevertheless this insect frequently causes extensive injury because when an outbreak occurs farmers and agricultural leaders may be taken by surprise. The problem is one of having an adequate supply of poison on hand before the outbreak occurs, since on account of the large acreage which is sometimes involved, the demand for poison to be used in one or two weeks may be greater than that used in a similar length of time for any other insect. Extensive stripping of cotton foliage has taken place over large areas because an adequate supply could not be secured until the damage was done.

The cotton leaf worm is a large, semi-looping, green or green and black striped caterpillar about an inch and a half long. It appears almost every year in the South during the summer, and feeds upon foliage and other green parts of the cotton plant. The cotton leaf worm is a native of the tropics and does not pass winter in the United States. This worm is the larva of a strong-flying moth which migrates northward into the Cotton Belt every year and deposits eggs on the foliage of cotton plants. The destructiveness depends upon the earliness with which the leaf worm occurs in large enough numbers in the Cotton Belt to strip cotton foliage. Usually the first few worms are found in the Gulf states in early July. The time of their occurrence in large enough numbers to strip cotton varies from late July to late September. If the invasion does not occur before September, the loss is generally negligible.

The destructiveness of cotton by the cotton leaf worm is variable from season to season. While it causes some local damage nearly every season, widespread losses occur only in occasional years when large numbers of the worms appear early in the season. When an outbreak occurs late enough in the season, the cotton leaf worm is sometimes thought to be an asset to the cotton grower. Stripping of foliage hastens the opening of bolls and thus facilitates harvest. The worm is also a competitor of the boll weevil for food, and by destroying the squares which are formed too late to make cotton it helps to prevent the development of the late-maturing boll weevils.

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*Alabama argillacea (Hbn.); family Noctuidae.

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This is a doubtful benefit, however, because worms feeding on cotton after the bolls are opening may cause damage by discoloring the lint with excrement.

The frequency with which the cotton leaf worm occurs may be illustrated by records in Arkansas. During the period of 20 years between 1922 and 1941, inclusive, there have been five statewide outbreaks. The years of these outbreaks were 1923, 1930, 1935, 1936, and 1941. During two years, 1928 and 1932, there was no injury. During the other years there was local injury with losses in some counties but no statewide injury.

The cotton leaf worm moths are nocturnal and generally feed, deposit eggs, and fly about by night. By day they hide among the cotton plants. Each female moth may deposit several hundred eggs, which are placed singly on the undersides of cotton leaves. The moths feed on nectar, juices of many plants, and juices of fruits with tender skins.

During the first few days after hatching, the cotton leaf worm, or larvae, feed on the undersides of the leaves on which they hatch. After they shed their skins the first time, they eat holes through the leaf and move up to the top of the plant to feed on the more tender foliage, stripping the cotton plants. When growth is complete the caterpillars draw parts of leaves together so as to cover themselves and spin a loose silken cocoon within which they transform to the pupal stage and later to the adult. About three weeks or one month is required to complete the life cycle. Successive generations do not necessarily develop on the same farm. The moths are strongly migratory and the worms found in a field are usually the offspring of moths that have developed farther south.

Control

The cotton leaf worm is easily controlled by the use of arsenical insecticides. Calcium arsenate is the most satisfactory poison to use whenever it is available. It should be applied at the rate of 3 to 4 pounds to the acre. If the dusting machinery will not distribute so small an amount of poison evenly, the calcium arsenate may be mixed with hydrated lime at the rate of one part of lime to one of poison in order to add bulk.

Since the application of an insecticide for the control of leaf worms is not necessary every season, a supply of calcium arsenate may not be readily available when an outbreak occurs. When an extensive outbreak is suddenly recognized and calcium arsenate cannot be obtained in time to prevent damage, a number of other arsenicals, such as powdered lead arsenate, magnesium arsenate, zinc arsenite, and Paris green, may be substituted for it. These insecticides are all more expensive than calcium arsenate, and are not as well suited for dusting. They should be substituted only when calcium arsenate is not available. The first three of these may be applied in the same manner as calcium arsenate. Paris green is a very effective poison, but it may produce burning of the cotton foliage. To secure the least amount of damage and best adhesion to the plant it should be applied in the following mixture: One part Paris green, one part flour, 4 parts hydrated lime. It should be used at the rate of 2 pounds of poison to the acre.

Dusting machinery, such as is used for boll weevil control, is most satisfactory in making dust applications to control the cotton leaf worm. When such equipment is not available a dusting outfit made of bags attached to either end of a pole of a length equal to the distance between two cotton rows, may be used. This pole is carried in front of a man on a mule ridden at a trot, so that it leaves a cloud of dust behind. It is usually best to make dust applications at night when the air is still. If a farmer is equipped for spraying but not for dusting, three pounds of lead arsenate or calcium arsenate should be used in 100 gallons of water.

Watchfulness is of first importance in the control of the cotton leaf worm. The grower should examine his fields frequently during the period of danger from the middle of July to early September. As soon as the first cotton leaf worms are found, the possible injury which may occur that season should be determined by taking into consideration the number of worms present and the relative maturity of the cotton. If there is danger of much loss, poison should be applied at once, either in spots or over whole fields, wherever the worm is found. It is always desirable to have a stock of calcium arsenate on hand before it is needed.

SUMMARY

Leaf feeding caterpillars and sawfly larvae are relatively easily killed by insecticidal applications if it is possible to cover during the period of infestation the leaf surface upon which they feed. The problems in control that arise are as often caused by the characteristics of the plant as of the insects themselves, as is shown by the types of problems discussed.

The imported cabbage worm is easily killed with arsenicals and rotenone but if spraying is depended on, a "sticker" must be added to the spray mixture to insure adhesion of the insecticide to the waxy leaf surface of many of its hosts. Since the foliage is used for food the insecticide applied within 30 days of harvest should not leave an objectionable residue, and under these conditions rotenone should be substituted for the less expensive and more durable arsenicals. On account of the large number of generations plants are subject to attack during a long period, and insecticidal applications should be made whenever injury threatens. In controlling this insect the problems presented by the host are most important.

The pecan leaf case bearer has only one generation a year and can be controlled by a single spray application in late summer, provided it is timed after the latest larvae have hatched and before the earliest larvae form their winter hibernacula. In the more humid pecan producing regions there is danger of injury to foliage from the insecticide. The height of pecan trees may add to the problem the requirement of high-powdered spraying machinery. The control of this insect depends upon a knowledge of seasonal history, as well as the problems presented by the host.

The cotton leaf worm is easily controlled by either dust or liquid application of arsenicals. There is no problem of spray injury, adhesion, machinery, or even of much expense. In this case failure may usually be charged to unpreparedness. On account of the large acreage of cotton local reserves of insecticides are quickly exhausted when it becomes generally known that an outbreak is underway. Watchfulness supported by the knowledge of when the pest is likely to occur, and a supply of insecticide on hand before it is needed are the principle requirements for success.

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CHAPTER XII

BEETLES WHICH ATTACK FOLIAGE BOTH AS LARVAE AND ADULTS

The larvae of leaf beetles of the family Chrysomelidae are the coleopterous counterparts of the larvae of the Lepidoptera. These beetle larvae occur in every habitat in which caterpillars are found. They have many representatives among the more important pests of truck crops. They are less frequently destructive as feeders on foliage of woody plants, although a few species like the elm leaf beetles and the poplar leaf beetle are well known pests of shade trees.

The problem of control of the chrysomelid larvae which feed on foliage is similar to that of leaf eating caterpillars. There are the same problems with relation to the host, that is, adhesion of the insecticide, susceptibility to spray injury, objectionable spray residue, etc. The problem of control may differ, however, because the adult leaf beetles are also foliage feeders while adult lepidopterons are not. With chrysomelids, the adult is sometimes the most destructive stage and usually the most difficult to kill. While most beetles with leaf eating larvae are of this family, there are a few others scattered throughout the order. In a single tribe of weevils, the Hyperini, the larvae are foliage feeders and are often associated with the adults on the foliage of the same hosts. The alfalfa weevil and clover leaf weevil are examples of this group. An aberrant group of leaf eaters also occurs among the lady beetles which are ordinarily predatory insects.

In this discussion we shall consider only those species which feed on foliage of the same plants both as adults and larvae. Those chrysomelids which are root feeders as larvae will receive attention in the next chapter.

THE COLORADO POTATO BEETLE

The Colorado potato beetle*feeds upon the foliage of the potato plant both in its larval and adult stages. Potentially it is capable of destroying the potato crop, and if it were not that it is relatively easy to control, this insect would be a very serious menace to potato production. When it first appeared as a pest it caused great alarm, for at that time the use of arsenical insecticides was not developed. The convex bretles, marked with 10 alternating black and tan stripes on their wing covers, and the stout reddish grubs are well known to every potato grower.

This beetle is a native of the Mexican plateau where it feeds upon wild plants of the genus Solanum, to which the potato belongs. It did not attract attention as a pest until after the potato plant was introduced within its range. In the 1850's it was recognized as a destructive insect. By 1859 it reached the banks of the Missouri River at Omaha, Nebraska; by 1864 it had crossed the Mississippi River into Illinois; ten years later it had crossed the country from potato patch to potato patch and was found in the Atlantic seaboard states. It now is well distributed wherever potatoes are grown in the United States and Canada.

The cultivated hosts of the potato beetle include potatoes and eggplant and occasionally tomatoes. It is seldom of importance on the latter crop except on newly transplanted plants, and sometimes in the seedbed. It also attacks weeds in the genus Solanum, which are of importance in distribution and in maintaining an infestation.

Under favorable conditions the life cycle has been completed in as brief a period as 31 days; incubation requiring 4 days; the larval feeding period, 10 days; the period in the soil, including prepupa, pupa, and callow adult, 10 days; and the preoviposition period, 7 days (2).

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*Leptinotarsa decimlineata (Say); family Chrysomelidae.

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The Colorado potato beetle passes winter in the ground below the frost line. Beetles begin to emerge about the time potatoes are coming through the soil and feed on the foliage. Deposition of eggs on potato leaves begins about two weeks after the earliest emergence and continues for about six weeks. The beetle is usually credited with having one or two generations a year. In Arkansas the potato beetle appears to be quite definitely a one generation species. Most beetles emerge from hibernation in April and deposit eggs from late April to June. Adults of the first brood mature from May until early July and after feeding for a few days bury themselves again and rest until the next spring. The entrance into the diapause occurs in spite of an abundance of food, of favorable temperature, and a season long enough to produce several generations. The active feeding period of the overwintered adults and of the larvae is in spring and early summer, during the period when foliage of early potatoes, or of their most important wild host in Arkansas, the horse nettle, is growing rapidly. This is the usual seasonal history but variations occur. Occasionally after a brief preoviposition period some of the newly transformed beetles reproduce and give rise to a second generation. Under artificial conditions the writer has secured four successive generations and Tower has reported five successive generations (3).

The injury by overwintered beetles and their offspring, and even by a direct second generation when it occurs, is to early potatoes. Sometimes there is injury to late potatoes in September. The larvae which are present on potatoes at this time are apparently offspring of beetles which entered the diapause in early summer and emerged from it in late summer. Intermittent periods of oviposition and resting in the soil have occurred with a few individuals in experimental lots.

The life of adult beetles is usually about one year, ending with the reproductive period the year following their maturity. Beetles usually die after reproduction is completed. Nevertheless, in experimental lots some adults have deposited eggs each of two years following maturity and spent the intervening winters in hibernation. Other beetles extended the period in the ground to two years, and began reproduction the second year after reaching the adult stage. This extended diapause may be of importance in carrying the species through an unfavorable season.

The Colorado potato beetle is now easily controlled by spraying with arsenicals. Arsenate of lead at the rate of one and a half pounds in 50 gallons of spray mixture is frequently recommended. Paris green was first used for potato beetle control and still has an advantage since it is a very active poison and the adult beetles are relatively hard to kill. On account of the large amount of water soluble arsenic it contains, however, it has been largely replaced by safer insecticides. Arsenite of zinc, which is more active than arsenate of lead is preferred in commercial potato producing regions and is recommended at the rate of two pounds in 50 gallons of water (1).

Aside from the choice of an insecticide the control of the Colorado potato beetle is an easy problem. The foliage is quite resistant to arsenical injury, even though it may be burned by Paris green. There is no spray residue problem. An aqueous spray adheres readily to the foliage and the plants are easily sprayed. The problem of timing is also relatively simple since the protective spray need not be applied until the beetles are in evidence. Usually one or two spray applications during a season will prevent injury.

THE GRAPE FLEA BEETLE

The grape flea beetle* feeds upon the buds and foliage of the grape. It is a local pest and it does not reduce the grape crop of the country as a whole to an

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*Altica chalybea Ill., family Chrysomelidae

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appreciable extent. Nevertheless in vineyards where it does occur it may destroy the greater part of the crop and it is difficult to prevent damage to buds after feeding has once begun. The difficulty in preventing injury forms a contrast with the control problem of the Colorado potato beetle.

The grape flea beetle is an irridescent steel blue beetle about a sixth of an inch long. The larva, which is the other stage commonly seen, is a stout grub about one-fourth of an inch long, black or yellowish with transverse black plates on each segment. This species has one generation a year. Winter is passed in the adult stage under leaves or trash in woodlands or fence rows around vineyards. The beetles come out of hibernation when the grape buds are swelling and attack them voraciously. It is at this time that the chief damage is done, for, in hollowing out a single bud, three or four potential grape clusters may be destroyed. The infestation is usually local and along the margins of vineyards, for the beetles do not migrate farther than is necessary to secure an adequate food supply.

After feeding for about two weeks the beetles begin to deposit eggs in groups under strips of bark and around the bud scales. The first eggs to be deposited may require two to three weeks to hatch although when temperatures are higher the egg stage may be passed in six days. The larvae feed on the grape leaves, eating the upper epidermis and part of the leaf tissue under it and leaving brownish chainlike marks on the upper surface of the foliage. This feeding seldom causes appreciable injury. When full grown they drop from the leaves and transform to the pupal stage and later to the adult in a cell formed about an inch below the surface of the ground. In the grape belts along the Lake Erie shore the larval feeding stages require an average of 24 days for development and the period in the soil an average of about 19 days. After the adults emerge they feed sparingly for some time and then go into hibernation.

When beetles appear in a vineyard in the spring the problem of control is very difficult. The buds expand so rapidly that it is impossible to keep them protected with spray unless a series of applications are made at very short intervals. In addition to this the beetles appear to be repelled by an arsenical poison. Spraying with arsenate of lead at the rate of three pounds to 50 gallons of spray mixture is recommended. Where this has been done experimentally, over half the crop has been saved in face of a very serious infestation.

If the injury is caused by beetles which develop within a vineyard and is anticipated the previous year, control may be easy. The larvae are surface feeders on the upper sides of the foliage where it is easy to apply poison. Furthermore they are easy to kill. A single spray application when the majority of the larvae are present will kill practically all of them and prevent damage the following year. As a rule it is recommended that a pound and a half of arsenate of lead to 50 gallons of spray be used in the spray application before grapes bloom which is about the best time to destroy flea beetle larvae. Weaker dosages probably would be effective so far as the larvae are concerned. Flea beetle injury is seldom of importance in vineyards which receive the regular spray applications unless there are wild grapes nearby, which are not sprayed (4). In flea beetle control the host presents no difficulties. Grape foliage is quite resistant to arsenical burning, and at the time of the year these applications occur no residue problem is involved.

THE MEXICAN BEAN BEETLE

The Mexican bean beetle* within its range is the most destructive pest of the bean plant. On unsprayed check plots in Connecticut it has reduced the crop from 37 to 67.5 per cent (9). This insect is probably a native of Mexico. It had been

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*Epilachna varivestis Muls., family Coccinellidae.

known to occur in the Mountain States of the arid west since 1850. In 1920 it appeared in Alabama and migrated rapidly eastward and northward until now in the eastern part of its range it is found in nearly all the states east of the Mississippi and has crossed the river into northeastern Arkansas. It has migrated as far as 200 miles in a single season. It is not equally important over its entire range, however, but is said to be most destructive in the Allegheny Mountains and the bordering foothills.

The Mexican bean beetle is a species in the family of lady beetles, most of which feed on other insects. Species of the sub-family to which it belongs, the Epilachninae, however, are phytophagous. This beetle resembles other lady beetles in a general way. The adult is a tan colored, hemispherical beetle, with 16 black spots on its dorsal aspect. The larvae are orange colored, about one-third of an inch long and are covered with branched spines.

The Mexican bean beetle is chiefly injurious to edible beans including snap beans, navy beans, and lima beans. Beggarweed (_Mebomia_ sp.) is the host next preferred. It will reproduce on cowpeas and soybeans but seldom causes extensive damage to these crops. The beetles and larvae feed on the under surface of the leaves of the plants attacked, eating strips of the lower epidermis and sometimes most of the leaf tissue skeletonizing the foliage. If the leaves are destroyed it will feed upon all green parts of the plant.

Under optimal conditions the bean beetle can pass through its immature stages, from egg to adult, in 33 days. This includes 5 or 6 days for incubation of eggs, 20 days for the larval stage, and 7 days for the pupal stage. After reaching the adult stage the beetle feeds for about two weeks before laying eggs. Single females have deposited over 1,600 eggs although the average is reported as less than 500. The eggs are deposited on end and in clusters on the under sides of the foliage of its hosts. The naked pupae are also usually found attached to the under sides of leaves.

Bean beetles hibernate in colonies under leaves, preferably in well drained woodlands. Usually the hibernation places are within a fourth of a mile from bean fields, although at times the distance is much greater. Beetles emerge from hibernation in the spring and frequently may be found on their hosts when the plants are small. In the southern states there may be three or four generations a year.

Control

The problem of control by insecticides differs from that of the leaf beetles just discussed in that throughout the humid part of its range the hosts are susceptible to spray burning. Spray residue is objectionable on beans when the pods are used for food. The fact that feeding is on the under sides of the foliage makes application of insecticides somewhat more difficult. On the other hand, the insect is easier to kill than the chrysomelids which have just been discussed.

As long as the range of the bean beetle was limited to the Arid West, spraying with arsenate of lead was recommended for control (6). When it appeared in the humid Southeast it was found that arsenical injury was so serious that this insecticide could not be used. Magnesium arsenate, used at the rate of one pound in 50 gallons of spray mixture, was first proposed as a substitute, since it causes less injury. In some years, however, even this arsenical produced spray burning. In the search for a safe insecticide cryolite, used at the rate of three pounds to 50 gallons, was next given consideration. At present a spray of derris or cube powder containing four per cent rotenone and used at the rate of $1\frac{1}{2}$ pounds in 50 gallons of water is believed to be the most desirable insecticide for this purpose. When spraying is

not practical the insecticide may be applied in the form of dust containing 0.5 per cent rotenone at the rate of 20 to 25 pounds to the acre. Insecticides bearing rotenone have the advantage of being non-injurious to bean foliage and of leaving no objectionable residue on the pods.

To secure good coverage of the under sides of foliage, angle nozzles on rods which will direct the spray upward and which are held about two inches above the ground are recommended. If these nozzles are mounted on traction sprayers there should be a short section of rubber hose near the ground to prevent snapping of the spray rod. Application of insecticides should be delayed until there is at least one egg group to each 10 feet of the row or until beetles are abundant enough to cause foliage injury.

SUMMARY

The control of beetles which feed on foliage both as larvae and adults differs from the control of caterpillars, since both stages of such beetles must be considered, while adults in the Lepidoptera are not directly destructive and seldom receive attention. The adult beetles are often more resistant to poison than their larvae and since they are more active avoid poisoned foliage and take advantage of imperfect coverage. With beetles, however, as with caterpillars the character of the host causes a part of the problem.

The Colorado potato beetle presents a relatively easy problem in control compared with that of many beetles because the leaf surface of the host plant is easily covered, insecticides adhere well to it, and the plant is relatively tolerant to arsenicals so that the most effective insecticides may be used.

By contrast the grape flea beetle is difficult to control although the insect itself is no more resistant to poison. When the adult emerges from hibernation and attacks the swelling buds it is not possible to keep the buds covered with an insecticide on account of their rapid increase in size at that period of development. On the other hand the larvae which appear after the leaves have expanded and feed on their upper surfaces are easily killed. Since the flea beetle has only one generation a year, the problem resolves itself into destruction of the larvae one season in order to prevent damage by the adults the next.

The Mexican bean beetle itself may be more easily poisoned than the two species just discussed. The problem which it presents is largely one of the host and is difficult because of the susceptibility of bean foliage to injury by arsenicals and the necessity of avoiding objectionable residue on the bean pods. Since both adults and larvae feed on the underside of foliage applications of insecticides to the under surface is necessary.

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CHAPTER XIII

BEETLES WHICH ATTACK FOLIAGE AS ADULTS AND ROOTS AS LARVAE

There are many species of beetles which attack foliage in the adult stage and roots of the same plants in the larval stage. As a rule these beetles present a more difficult problem than species which feed upon foliage both in adult and larval stages, since it is usually not possible to apply control measures to the larvae in the soil and control must be directed against the adults. Most of the beetles which fall into this category are leaf beetles, in the family Chrysomelidae, and in the sub-families Eumolpinae, Galerucinae, and Halticinae. These beetles may be divided into two rather distinct groups with respect to seasonal history and larval characteristics. Among the better known species of the group included in the Eumolpinae are the grape rootworm, the cranberry rootworm, and the strawberry rootworm. The larvae of all of these are relatively stout, in a way resembling white grubs. Most of these species have one generation a year and pass winter as larvae. Among species of the other group included in the Galerucinae and part of the Halticinae, are the striped cucumber beetle, the bean leaf beetle, and the potato flea beetle. The larvae of these beetles are very slender. These species usually have more than one generation a year and pass winter in the adult stage. Practically all truck crops are attacked by some species of small leaf beetle which feeds on the roots of the same crops in the larval stage.

THE GRAPE ROOTWORM

The grape rootworm* is a first rate pest of grapes in the grape growing regions of the United States east of the Rocky Mountains. The adults feed on the upper surface of grape leaves, while the larvae feed upon the roots. Probably the greater injury is caused by the larval feeding. The attack is insidious and more frequently results in reduction of vigor of the vines and decreased yield than in outright killing of the vines. The larvae eat the root fibers and if abundant strip the bark from the larger roots and the underground stem. The feeding on the foliage by the adults is readily recognized by the chain-like feeding marks on the upper surface of the leaves. This injury is conspicuous but results in acute damage less frequently than the larval injury, although when the beetles are abundant considerable leaf surface is destroyed and defoliation may follow. In Arkansas and Missouri the adults may also feed on the green grape berries (2). The species is generally distributed in the northern grape regions and occurs in all vineyards in some numbers. In the South it is less generally distributed but is fully as destructive where it occurs.

The adult beetle is grayish brown in color and about one-fourth of an inch long. The larva is white and resembles a very small white grub in general appearance. The grape and the Virginia creeper are the only hosts of this insect.

There is usually one generation a year. Winter is passed by the nearly grown larvae below the frost line. In the northern vineyards the larvae return near the surface of the soil in the spring where they feed for a few weeks. When fully grown they form their pupal cells within two or three inches of the surface of the soil. In the Lake Erie grape belt the average duration of the pupal stage is 17 days (3). While the emergence of adults from the soil may be extended for over a month, the majority of them appear after the end of the blooming period of Concord grapes. After the adults emerge they spend two weeks or more in feeding before beginning oviposition. The eggs are deposited in groups on the vines under strips of bark. When the larvae hatch they drop to the ground where they feed until about three-fourths grown and then burrow deep into the soil to hibernate. The next spring they renew their attack on the grape roots and begin a new seasonal cycle (1, 3).

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*Fidia viticida Walsh; family Chrysomelidae.

The seasonal history in Arkansas differs from this in that those larvae which pupate and transform to the adult stage do not feed during the spring of that year but have completed their larval development the previous season. Those larvae whose development is not completed the first season and feed in the spring do not pupate until the second year. Thus some individuals require 2 years for the life cycle (2).

Control

The larvae spend about ten and a half months or more in the soil. During this long period they are relatively safe from control measures. Possibly some form of soil fumigation might be used to destroy them but the acre value of the grape crop might not justify this expense. Breaking the pupal cells by cultivation is recommended in the Lake Erie grape region as a supplementary measure of control (3). The main dependence, however, is placed upon destruction of the adults by spraying.

The beetle is particularly accessible to control by spraying because it feeds upon the upper surface of grape foliage which is easy to cover. The long preoviposition period also gives the grape grower time to make the application in the interval between emergence of the beetles and the beginning of reproduction. The fact that the emergence from the soil of the majority of beetles is concentrated within a few days is another weakness in the seasonal history of the species. During the first few days after emergence from the soil the beetles feed voraciously. Grape foliage is relatively resistant to arsenical burning and spray adheres readily to its surface.

In the northern grape regions one spray application, including one and one-half pounds of arsenate of lead in 50 gallons of spray mixture applied soon after the beetles first appear, will usually prevent serious injury by this pest. This application is usually the first after grapes bloom. In heavily infested vineyards a second application may be necessary. Spraying with arsenate of lead does not kill all the beetles since many of them are repelled by the poison. It gives adequate protection, however, to the vineyard (1, 3).

In Arkansas if infestations are severe, spraying with arsenate of lead has not given satisfactory control. Instead derris powder containing 4 per cent rotenone and used at the rate of 1½ pounds to 50 gallons has been effective (2).

THE STRIPED CUCUMBER BEETLE

The striped cucumber beetle* is the most important insect pest attacking cucurbit crops within its range, which includes all of the United States east of the Rocky Mountains. It may destroy stands of seedlings outright as soon as they appear in the spring, and is a constant menace to its hosts until harvest. It is of variable importance in different parts of its range, in some situations being a limited factor in the production of certain of its hosts, while in other parts of the same region it may be practically negligible.

Cantaloupes, cucumbers, watermelons, and hubbard and marrow squashes are the crops which are most severely injured. Summer squashes and pumpkins are less frequently damaged, although they furnish food for the beetle larvae late in the season after most of the commercial plantings of cucumbers and cantaloupes are no longer available. In this way these hosts make possible the development of a late brood of beetles and are important in increasing the number which enter hibernation.

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*Diabrotica vittata (Fab.); family Chrysomelidae.

The most important damage is caused in the spring by the feeding of overwintered beetles upon seedling plants, which frequently results in a total destruction of stand. Late in the season the beetles feed upon foliage and may destroy flowers and small fruits or scar the surfaces of larger fruits, rendering them unfit for sale. The larvae feed upon the underground stems and roots but usually do not cause as acute damage as the adults. After plants begin to send out runners, they are seldom killed outright by this insect, although their productiveness may be reduced. The striped cucumber beetle also transmits diseases attacking cucurbits, particularly bacterial wilt.

Life History and Seasonal History

The adult beetle is about one-fifth of an inch long and its dorsal aspect is marked with four yellow and three black stripes. The small orange or yellow colored oval eggs are deposited in the soil around their hosts. The larvae are white and very slender and when full grown are about half an inch long. When full grown they form a pupal cell near the surface of the soil.

From 40 to 45 days are required to complete the life cycle from egg to egg under favorable conditions in summer. The incubation period is about 8 days, the larval feeding period about 18 days, the period in the pupal cell which includes the prepupa, the pupa and the callow adult, requires about 13 days. After the adults emerge from their pupal cells they feed from 5 to 7 days before beginning to deposit eggs. The period of oviposition may extend over a month. During this period beetles may deposit several hundred eggs. A single female has been recorded as having deposited a total of 1,514 eggs.

The female beetles do not deposit eggs readily, neither do eggs hatch, nor larvae develop, in a dry soil. A reasonable amount of soil moisture is essential if the immature stages are to be passed successfully. For this reason, the cucumber beetle is often of negligible importance in upland fields while at the same time it is a serious problem in nearby bottoms. The increase in numbers is also checked by dry summers.

The striped cucumber beetle comes out of hibernation in early spring, about the time the earliest cucumbers and melons are planted. This brood consists of beetles of the second and later generations of the previous year. The beetles which hibernate in wooded ravines may be active earlier than this on warm days of March. Cucurbits which are grown near places favorable for hibernation are usually attacked as soon as they come up and occasionally the beetles even burrow into the ground to meet them. Fields which are distant from suitable places for hibernation may not be attacked for two or three weeks after the beetles are out, and if the plants are well started by this time the injury is not so likely to be severe.

When the spring is marked by intervals of warm and cool days, the beetles appear and disappear, depending upon the weather. The period of heavy injury by the beetles of the over-wintered brood usually coincides with the period when most plantings of cantaloupes appear above ground. After feeding for about two weeks, beetles become less active and migrate less from field to field. This is a period of heavy oviposition. They spend most of the day just beneath the surface of the ground around the stems of plants. Most of the overwintered beetles die within six weeks after emergence, although a very few may live through midsummer. Before all of the over-wintered beetles have died, beetles of the first generation appear in the fields. Beetles newly emerged from the soil are readily recognized since the yellow stripes are pale and often nearly white. After feeding for a few days they begin reproducing and may give rise to a succeeding generation.

The number of generations which occur in a year is indeterminate and depends upon the length of the season. In localities in the South where the season is long enough for three generations to occur and where no late cucurbits are grown, most of the third generation is prevented from development (5, 6).

Control

The problem of control of the striped cucumber beetle differs from that of the grape rootworm in that the injury by the adults is more important than that by the larvae. There is no seasonal regularity regarding the time when beetles appear in fields, and hence a spray schedule cannot be depended upon, although protection is more important to seedling plants than to older ones. When the adults appear in destructive numbers prompt action is necessary.

When the infestation is light the application of an arsenical either in combination with a fungicide or with a diluent appears to give adequate protection to plants. For this purpose a spray including 1½ pounds of arsenate of lead in 50 gallons of Bordeaux mixture (6) or a dust including one pound of calcium arsenate in 19 pounds of gypsum (5) or calcium arsenate in a copper dust diluted with talc have been recommended. Such insecticidal combinations are often effective as repellants rather than as insecticides, although a few beetles are killed. Where infestations are severe, arsenical poisons have not always prevented destruction of stands.

Insecticidal dusts containing flourine or rotenone have been found to be effective in controlling the striped cucumber beetle. Sodium fluosilicate diluted with equal parts of talc, a barium fluosilicate compound containing 80 per cent of the insecticide, and cryolite have all been used in cucumber beetle control (1). Under some conditions these insecticides may injure the host plants. If applied heavily the injury may be severe. They are also more likely to cause damage during rainy weather than during dry weather. Possibly for this reason the fluosilicates appear to be more in favor in the western part of the range of the cucumber beetle than in the more humid east. Excessive dilution of these insecticides has been a cause of dissatisfaction because an increase in the proportion of the diluent does not reduce the tendency to plant injury, unless the amount of the fluosilicate applied on the plant is actually less, but does reduce the insecticidal efficiency (6,7).

Dusts containing .5 to .75 per cent rotenone are often preferred for control of the cucumber beetle. Ground derris root mixed with several inert dusts and containing .6 per cent rotenone killed from 95 to over 98 per cent of all beetles in a series of experimental tests made in Wisconsin in 1940 (4).

THE JAPANESE BEETLE

Beetles which are foliage feeders as adults and whose larvae feed on roots of other plants, present one of the most difficult problems of insect control. The most destructive of these beetles are leaf chafers in the family Scarabaeidae. These beetles are usually more difficult to poison than species of the family Chrysomelidae. Since the larvae attack other plants which may grow on land not under control of the farmer whose crops are injured by the adults, it is often difficult to direct control measures against both adult and larval stages.

Among the species of the Scarabaeidae which are most destructive in the adult stage is the Japanese beetle*. This beetle is a rather general feeder not only on foliage but upon ripening fruit, and consequently the measures for its control must

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*_Popillia japonica_ Newm.

be varied to suit the condition of the host to be protected. On account of the difficulty and importance of the problem spraying experiments for its control have been more extensive than for any other related species. This makes it an unusually suitable subject to illustrate this type of a problem.

The bionomics of the Japanese beetle and its control by fumigants have been discussed in chapter IX.

Control

The difficulty in controlling the Japanese beetle is due first to its great abundance throughout most of its range. For instance it was reported (9) that 13 tubs of beetles were collected from 156 early peach trees in the vicinity of Moorestown, New Jersey. Two days later the beetles again appeared to be as numerous as ever on the same trees. Where beetles are so abundant shade trees may be stripped in three or four days. The beetles are gregarious and are strong fliers and tend to concentrate their attacks on plants where other beetles are feeding. They have a wide range of hosts including fruit, field and vegetable crops, shade trees, shrubs, and flowers. The beetles attack plants on which they have not developed and move from one property to another so that control by indirect means by the individual is not possible. They may destroy plants in the small home yard which are often highly valued as well as in large areas of commercial crop production. On account of these difficulties plant protection is stressed while killing the insect is secondary. Plant protection is often secured by repellant action rather than by the insecticidal qualities of the spray material.

Arsenate of lead is repellant to the Japanese beetle, possibly because of toxic symptoms which it induces. Although there is some feeding upon foliage sprayed with this insecticide, beetles tend to leave before they have eaten a lethal dose. Spraying materials like hydrated lime which leave a white deposit are also repellant. For protection of most shade trees, shrubs, and late apple trees, spraying with arsenate of lead at the rate of three pounds in 50 gallons of water is generally recommended. To this three-fourths pint of light pressed fish oil is added to improve the adhesion. On plants which will not tolerate arsenate of lead or on which it is desired to avoid arsenical residue, like plants about the home yard and ripening fruits, spraying with a mixture of ten pounds of hydrated lime and two and a half pounds of aluminum sulfate is recommended. This recommendation is made for summer apples, late peaches, and many ornamentals. If this heavy application of lime cannot be tolerated, as is true of ripening peaches, spraying with one and a half pounds of a powder containing four per cent rotenone plus one and a half pounds of rosin residue emulsion in 50 gallons is recommended. Protection is required throughout the entire season when the beetles are active. It may be necessary to renew the coatings of arsenate of lead or lime before they weather off, if there is much terminal growth. Applications of rotenone must be made every seven to ten days. Spraying to protect ripening fruits must be supplemented by sanitary measures. Since beetles are attracted to ripening or injured fruits, such fruits should be picked and removed from the orchard daily.

Corn silks and leafy vegetables may be protected by dusting with hydrated lime which is useful as a repellant. There is no adequate protection for such fruits as ripening raspberries since they will not tolerate lime, nor flowers coming into bloom, because lime largely destroys their ornamental value.

Arsenate of lead coated with lead oleate is not as repellant to the beetles as uncoated arsenicals. Green arsenate of lead is also less repellent. For this reason these materials were at times preferred to uncoated arsenate of lead for Japanese beetle control. They killed more beetles but the plants on which they were applied were more severely injured than plants sprayed with uncoated arsenate of lead.

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Spraying shade trees requires equipment somewhat larger than for orchard spraying. Where trees as high as 90 feet are to be sprayed it is recommended that the sprayer be equipped with a 20 to 25 horse power engine, a pump capable of delivering 40 gallons a minute at 400 pounds pressure, and a tank capacity of not less than 400 gallons. The hose should be about 300 feet long. The spray should be applied with a solid stream nozzle with a spreader used for the lower branches. A spraying crew should include, in addition to the man who operates the spray gun, extra men to pull the hose. Since most shade trees are on lawns or along streets, the ownership and operation of equipment of this sort must be a community enterprise and usually must be sponsored by a city or civic group (12). In timing spraying of shade trees it is desirable that the application be made as late in the season as possible and yet before injury begins. This requires close observation on seasonal development.

The larvae in sod may also be controlled by the use of arsenate of lead. Soil fumigation to destroy larvae is of value in producing immediate results. It does not give permanent protection however. Soil may be "grub proofed" for a period of several years by treating with arsenate of lead. Usually an application of ten pounds to 1,000 square feet is recommended. The arsenate of lead may be applied to the surface of the sod with a sprayer or when mixed with a dry filler may be distributed over the surface of the soil with a fertilizer distributor. Hand distribution is likely to be uneven. It may be carried into the soil by water or rain may be depended upon for this. "Grub proofing" is obviously an expensive measure (8).

SUMMARY

Species of beetles which feed upon foliage while their larvae feed upon roots present a more involved problem in control than those which feed upon foliage in both adult and larval stages.

Damage to grape plants caused by rootworms as larvae is greater than that caused by adults. No insecticidal control of the larva is known and for this reason it is necessary to destroy the adults to prevent larval damage. Arsenical insecticides are somewhat repellant to the beetles. Although arsenicals give the foliage a degree of protection, the beetles are much more readily killed by rotenone. Insecticidal treatments should be applied during the brief period after the newly developed beetles emerge from the soil when they are feeding voraciously and before egg deposition begins. The fact that it has only one host simplifies the control problem.

The striped cucumber beetle like the grape rootworm is accessible to direct control only in the adult stage, but it is the adult that is the most destructive. This insect is also repelled by arsenicals. It is accessible to control either by flourine insecticides or by rotenone, and local conditions may determine the choice made. The host plants require protection most when in the seedling stages, but serious injury may occur at any other time during the development of the crop when beetles are abundant. There may be as many as three generations a year, and a number of insecticidal treatments may be necessary for control. Timing applications must be determined by abundance of the beetles. Unlike the rootworm it has a number of hosts but all are included in a single plant family.

The Japanese beetle is so destructive that the repellant character of the spray material is considered as more important than its effectiveness in killing the insects. The necessity for immediate protection is made acute because the pest occurs in such numbers that if not repelled they may destroy foliage while consuming a lethal dose. Its gregarious and migratory tendencies and its wide host range have added to the difficulty of the problem. Infestations occur in cities and may damage highly valued ornamentals which justifies relatively expensive control measures. The materials used for spraying or dusting plants include lead arsenate, hydrated lime and rotenone;

the choice is determined by the tolerance of the plant. Lead arsenate mixed with soil is also used for "grub proofing" turf. There is only one generation a year but the period of occurrence of adults, which corresponds to the period when plant protection is needed, extends throughout the summer months.

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CHAPTER XIV

SPRAYING SCHEDULES AND CODLING MOTH CONTROL

For the control of most of the insects studied hitherto, insecticides may be applied after the pest itself is in evidence. The timing of applications is dependent in large part on observation, and a knowledge of life and seasonal history serves merely to suggest the probable time that observations should be made. This method of timing cannot be relied upon for the control of insects that feed within fruits and stems, for such insects must be killed before entry is effected and before the insect is observed. Spray applications made with this purpose follow a schedule based on an intimate study of the life history and seasonal history of the pest concerned, and this information must be more detailed and exact than that used as a guide for observations on the time of occurrence of leaf feeders. In effect a spray schedule is based on a forecast or a prediction of the time of occurrence of the susceptible stage of the pest to be controlled. Spray schedules are used mostly for insects attacking fruits directly. Most of these pests are in the families Eucosmidae in the order Lepidoptera, Curculionidae in the order Coleoptera, and Trypetidae in the order Diptera.

THE CODLING MOTH

The codling moth* is the most destructive insect pest of the apple and its control is probably the most important problem of apple production. It is an example of an insect whose control depends upon closely following a schedule of spray applications timed by its seasonal history. Spraying cannot be delayed until the pest is in evidence, because the insecticide must be on the fruit it is expected to protect before the larvae hatch. Furthermore, the insecticidal protection must be maintained throughout the entire period during which infestation may take place. Accurate timing of applications, therefore, is the first requisite of control, and this depends upon an accurate knowledge of the time of the period of hatching. The requirements are so exacting that any degree of failure in these points leads to a proportionate degree of failure in control.

There is a wealth of information regarding the codling moth. Studies of life history and control have been conducted by the U. S. Bureau of Entomology in practically all of the apple producing states of the country. These investigations are similar in scope and plan and are readily compared with each other. Taken together they afford a picture of the effect of varying climate and geographical distribution upon the species and upon the problem of its control. In addition to these studies, the codling moth has received attention from State Experiment Stations wherever apples are grown. These investigations represent a diversity of methods of approach, a desirable feature in the study of any difficult problem. They frequently cover periods of 10 years or more, and thus record seasonal variations. The extraordinary attention centered upon this insect is shown by the fact that for the 30 year period from 1904 to 1934, inclusive, 1,828 papers relating to the codling moth are listed in the Banks and Colcord Indices. This concentration of study of a single species is a result of the recognition by apple growers of its dominating importance in the production of their crop. They not only demand information but utilize it to an unusual degree. In spite of all this investigation, the control measures now recommended are not altogether satisfactory. The mass of detailed information, however, makes the codling moth an unusually suitable species for study.

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*_Carpocapsa pomonella_ (L.)

The codling moth belongs to the Lepidopterous family Eucosmidae. Closely related to it are a number of important pests of deciduous fruits, among which are the Oriental fruit moth* and the grape-berry moth**.

The world distribution of the codling moth coincides with the distribution of the apple. It occurs in all apple producing regions of the U. S. Its original home is probably in Asia Minor, the presumed home of the apple (31).

Hosts and Injury

The codling moth is a pest of all pome fruits. There is a local race in California which attacks Persian walnuts (5). Apricots and plums have also been reported as subject to attack (25, 32). It has received most attention as a pest of apples and pears, and as such, it will be given consideration here. The injury caused by the codling moth is due to the larval feeding within the fruit. If this occurs early in the season, the fruit drops and is worthless. Very late injury causes "wormy" apples which remain on the tree until harvest and such fruit may have some sale value.

The amount of injury which the codling moth causes varies with the region and the season. Local conditions may cause further variation. In general, injury is relatively light in the more northern apple regions and is proportionately greater in the regions of more southern latitude. "In the complete absence of control measures,"Hyslop (13) estimates that the loss would "range from 10 to 20 per cent in the extreme northeastern part of the country to a total loss *** in most of the apple producing sections of the United States." The species tends to become more destructive in regions with relatively long seasons, which make possible the development of a greater number of generations, or in regions where the temperature is relatively high.

The regional variation in injury is shown by comparing records from various states. In Maine the codling moth injury seldom exceeds one per cent of the total crop (9) and in this state a single spray aplication for its control has been recommended (29). In the Champlain Valley of New York the damage in 1933 was estimated at two to nine per cent and in unsprayed orchards about 25 per cent (24). In Delaware in 1933 the calyx spray and three cover sprays invariably produce 98 per cent clean fruit, according to Stearns (33). In that state there is a large proportion of early varieties, 43 per cent, which doubtless reduces the severity of the problem. In Pennsylvania a survey was made of 1,251 orchards between 1929 and 1933, inclusive. In those in which control measures were considered satisfactory the loss ranged from one per cent to three per cent and in those considered unsatisfactory it ranged from eight to 13 per cent (12). Such data would make it appear that the problem of codling moth control is not difficult and is well in hand along the northern border of the United States.

On the other hand, heavy losses due to codling moth are generally reported from the more southern apple regions. A total loss of the apples on unsprayed trees is expected in Arkansas, southern Illinois, southern Kansas, in the Pecos Valley of New Mexico, in the Grand Valley of Colorado, and in the Pacific Northwest. Even in many sprayed orchards in northwestern Arkansas more than 50 per cent of the fruit has been infested and results even in plots sprayed experimentally in 1933 showed an infestation of over 30 per cent (15). In the Pacific Northwest, Webster (42) reports an average "worminess" of 26.6 per cent in sprayed plots. Even in a northern state the loss is sometimes severe. As for instance in western New York, Parrott reports a loss due to codling moth in 1933 of 35 to 75 per cent (24).

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*Grapholitha molesta (Busck)
**Polychrosis viteana (Clem.)

The tremendous cost of spraying operations aimed at its control is evidence of its destructiveness. Probably more is expended for control of the codling moth in the United States than for the control of any other insect pest attacking crops, although the apple crop itself is by no means the most important. In all of the more southern apple regions codling moth control is without question the most expensive operation of apple production. In southern Indiana this cost has been estimated at 40 per cent of the total cost of apple production (38). The annual cost of control for the country as a whole has been estimated at $17,500,000 (13). The codling moth will probably limit the advance of profitable production of apples except very early varieties in regions further south in the United States than where apple production now occurs.

Life History

The adult codling moth deposits eggs singly on the foliage or fruit of its hosts. Upon hatching the larva makes its way to the fruit if not already upon it, and as soon as possible buries itself within it. It remains within the fruit during the entire larval feeding period. When full grown it usually leaves the fruit to spin its cocoon under bark scales or in some other protected place. Here it remains as prepupa, then transforms to the pupal and finally to the adult stage. After leaving the cocoon the adult spends a short time, the pre-oviposition period, before becoming sexually mature, after which reproduction begins.

The time required for development from egg to egg varies with climatic conditions, which in turn vary with the region. As for instance in Arkansas (14), the codling moth may pass its complete life cycle from egg to egg in about 37 days. The average minimum incubation period is near 5 days; and the larval feeding period, 16 days; the period in cocoon, 14 days; and preoviposition will average about 2 days. The period in the cocoon may be divided into the prepupal period of about 5 days and the pupal period of about 9 days. This does not represent the absolute minimum but is about the average during midsummer when development is most rapid.

In the more northern apple belts the development of the codling moth is slower. For instance at Winthrop, Maine (29), 62 days are required to pass the immature stages, from egg to adult; in northwestern Pennsylvania (7), 53 days are required; at Yakima, Washington 44 days are required (20). In the fruit regions of the central and mountain states the minimum developmental period is similar to that of Yakima or approaches the rapid development in the Ozarks. The slowest development recorded is not in the extreme north but in the Santa Clara Valley of California (18), where although the season is long, summer temperatures are relatively cool. A minimum of 79 days is required for development of immature stages there.

As has been indicated, the rate of development is largely a response to temperature. In an elaborate study of the rate of development at Flora, Illinois, Glenn (6) concluded that the optimum temperature for development of the codling moth was between 86° and 88° F. His studies were not made with all conditions controlled and show some irregularities, but are highly suggestive. The average period of development of the pupal period will illustrate the effect of temperature on the rate of development of this insect.

Table 3. Time required for pupal development of the codling moth as affected by temperature. (Adapted from data presented by Glenn).

Mean Temperature °F.	Duration of stage. Days	Mean Temperature °F.	Duration of stage. Days
55.70	35.20	74.92	10.73
58.50	27.71	76.77	10.02
62.75	22.21	79.74	9.44
66.59	17.41	80.88	9.43
70.79	12.70	82.68	9.24

The fecundity of the codling moth, like its rate of development, is determined to quite an extent by temperature. Moths do not usually deposit eggs at a temperature below 62° F. and at this point the rate of egg deposition is very low. Physiological development and oviposition increase with rising temperatures. The temperature favorable for the greatest total oviposition is a mean of 77° F. The average number of eggs deposited at this temperature is a little over 150, although there is a record of a single moth depositing 345 eggs. More eggs are deposited on single days when the mean is higher until 80.6° is reached, but as the temperature increases the length of life decreases and the total oviposition for the entire life of the moth is less than at 77°. Above a daily mean temperature of 81° F. daily oviposition declines rapidly. Excessively high daily mean temperatures, that is, above 86° F., terminate the oviposition period of most moths, and may also produce sterility of eggs deposited. As the temperature falls below 77° F. physiological activity and daily oviposition declines and the life of the moth is prolonged until the mean temperature drops below 60° F., when the period of oviposition may extend to about two weeks. On the first day of oviposition an average of about 20 per cent of its eggs are deposited. The number declines regularly as the moths grow older. During summer, 90 per cent of the eggs are deposited in 7 days; during spring, the same percentage is deposited in 12 days (16).

The effect of mean temperature upon mean daily oviposition based on data from Arkansas (16) is shown by the following table.

Table 4. Average Daily Oviposition at Mean Temperatures Ranging from 59° to 91.4° F.

Mean daily temperature	Female moths	Eggs deposited daily (average)	Calculated mean
°F	Number	Number	Number
59.0	24	2.00 ± 0.83	2.15
64.4	51	5.65 ± 1.67	5.25
69.8	164	10.41 ± .99	9.43
75.2	393	14.43 ± .95	14.91
80.6	266	20.77 ± 1.34	19.10
86.0	125	17.10 ± 1.66	16.48
91.4	12	7.00 ± 2.89	11.15

In a general way an increase in temperature tends to increase the daily oviposition of the codling moth. Under climatic conditions which usually prevail in apple producing regions, usually the years of relatively high temperatures have been years of heavy infestation also. While oviposition may be expected to decline when the optimum temperature is exceeded, during most seasons the daily mean temperature seldom

rises above the optimum for enough days in succession to produce results that would attract attention in the field. Nevertheless, during some seasons excessively high temperatures occur for long enough periods to repress reproduction noticeably. The reduction in codling moth infestation was evident in orchards in Arkansas during the exceptionally hot summers of 1934 and 1936, when a heavy worm population in orchards in mid-July declined rapidly with the advance of the season and was almost negligible in late August. This was easily observed by the reduction of infestation of the fruit. It was shown later by decline in number of worms collected under bands, and this was followed in about two weeks by a similar decline in number of moths collected in bait traps (15).

Seasonal History

The codling moth passes winter in its cocoon as a full grown larva. As temperature rises above 50° F. development begins, and during the spring the larvae transform to pupae. Pupation obviously begins much earlier in more southern than in more northern latitudes. In Arkansas the earliest moths emerge from their cocoons in April while the last moths of the overwintered brood may not emerge until June. A succession of generations follows which appears to be adapted to the length of the season. Strictly speaking there may be only one complete generation a year since a few individuals of the first generation do not pupate during the year of their larval development but pass through winter before transformation. In northwestern Arkansas about 1½ per cent of the larvae of the first generation hibernate. About 15 per cent of the second generation hibernate, but the remaining 85 per cent transform and give rise to a third generation. The majority of the third generation, however, pass winter and the part transforming as a fourth generation is relatively small. Thus Arkansas is said to have three generations and a partial fourth (14).

The number of generations a year in a region seems to be adapted to the length of the season, or to the total accumulated summer temperature. In one of the most southern apple regions at Cornelia, Georgia (39), moths may begin emerging as early as March 25. Four generations and a partial fifth have been reared there. In the Pecos Valley of New Mexico (26), emergence begins between April 7 and 12 and there at least four generations occur. In Arkansas emergence may begin as early as April 13 or as late as April 30, and as stated there may be as many as three and a partial fourth generation. At Winchester, Virginia (1), in central Illinois at Flora (6), and in the Rogue River Valley of Oregon (45), emergence begins between April 21 and 27 and there are three generations. In Delaware (27), in the Grand Valley of Colorado (30), and in the Yakima Valley of Washington (20), emergence begins between May 10 and 20, and two generations with a trace of a third occur. In northern Pennsylvania (7), emergence of moths begins between May 30 and June 17; here one generation and a partial second occurs. At Winthrop, Maine (29), emergence begins in the last half of June and a single generation with a trace of second occurs. As previously stated, the length of the season is not the only factor; accumulated temperature must be considered. In the Santa Clara Valley of California (18), moths begin emerging in March, as early as in Georgia, but only two generations occur, because low temperatures prevail through the summer. While the number of generations in a given region seems to be adapted to the usual length of the season, it probably does not vary with the climate from year to year. In a region in which there is ample time for the development of three generations, a three generation strain is dominant.

The first generation is usually least destructive. This is because a large percentage of hibernating larvae fail to survive due to various causes, and because many of the moths of the spring brood emerge under conditions unfavorable for reproduction. Normally each of the successive generations is larger than the preceding, with the result that the worms occur in greatest numbers near the end of the season. There are no efficient natural enemies. The only natural checks during summer are shortage

of food and abnormally high temperatures. On unsprayed trees the infestation by the first and second broods may destroy practically all fruit with the result that larvae can not develop. For this reason the numbers of larvae collected under bands on unsprayed trees frequently decline after midsummer, while those in sprayed orchards increase until near the end of the season.

There are two periods of hatching of worms. The first generation is fairly distinct. The second and later generations, where they occur, overlap. The break between the first and second generation may not be complete in the southern apple regions, but is easily recognized. In the northern belts the break between generations is more distinct and longer.

When the hatching period ends fruit no longer requires protection. The approach of the end of hatching is indicated when the majority of larvae cease pupation but enter hibernation. This change is not abrupt, for in Arkansas some larvae enter hibernation four months before late apple harvest. The number entering hibernation increases until the generation which is numerically dominant for the region has time to develop. In a given region this may be later following cool summers, than following a summer with relatively high temperature.

Habits

The adult moth is crepuscular, that is, the period of its greatest activity is about twilight. Most eggs are deposited in dilute light, after sunset or on dark days and when the temperature is above 62° F. Eggs are deposited on foliage or on the fruits.

The larvae do not necessarily enter the fruit at once upon hatching, but may wander extensively over fruit and foliage, sometimes for a distance of 10 feet from the point of hatching, in search of a suitable point to enter fruit (34). Larvae prefer to enter fruits at some rough point on the surface. For this reason a majority attempt entry at the calyx end of the apple. Where apples are scarred by hail, by apple scab, by curculio feeding, or for any other reason, these roughened spots are likely to be located by worms hunting for points of entry.

The full grown larva spins its cocoon most frequently under bark scales on the trunk or larger branches of the tree. Occasionally cocoons are spun under stones on the ground, in the ground about the base of the tree, or in the fruits themselves.

Causes of Variations in Abundance

The causes of variation in average abundance from one apple belt to another are generally ascribed to length of season or to accumulated effective temperatures. As already indicated, these differences may determine the rate of reproduction of the codling moth and limit the number of generations that may occur. Seasons themselves also differ and for this reason the worm problem in a given locality varies greatly from one year to another.

The variations in codling moth injury in northwestern Arkansas (16), between 1918 and 1937 inclusive, will illustrate the extent of seasonal differences. During this period there were three years, 1919, 1922, and 1935, when injury to the apple crop in well-kept orchards was negligible and the same was true in most orchards in 1937. In addition there were three other years of light injury, 1923, 1924, and 1928. There were four other years, 1918, 1925, 1932, and 1933, when the crop loss exceeded 50 per cent even in heavily sprayed orchards. The negligible infestation of 1922 and 1937 may be charged to the total crop loss due to a late spring frost in 1921 and a similar loss in most orchards in 1936. These crop failures prevented the

development of nearly all moths during those years and as a result the numbers of overwintered moths which emerged the succeeding seasons were very small. Among the other factors which have been responsible for this variation in abundance, the climatic conditions at the time of flight of moths of the overwintered brood appear to be most important. During the severe years, 1918, 1925, 1932, and 1933, the temperature during May and June was distinctly above normal and consequently favorable to oviposition. During the light years, 1919, 1923, 1924, 1928, and 1935, the temperature during this period was below the mean. It is more difficult to find a consistent relationship between summer weather and codling moth abundance. Summer temperatures are always high enough to be near the range of temperature favorable for development and reproduction, although during the excessively high temperatures of 1934 and 1936 threatening codling moth infestations declined rather than increased.

It frequently happens that the worm problem differs in adjacent orchards or even in various parts of the same orchard. While such differences are not always easily explained, local infestation is usually modified by the accumulated infestation carried from one season to another, by the combination of varieties grown, by the proximity of other sources of infestation, and by differences in local temperature.

The accumulated infestation which may be carried over in an orchard from one season to the next is reduced in proportion to the earliness of the varieties grown. The codling moth is not a problem in the southern apple regions in isolated blocks of early summer apples, since there is no fruit upon which the late generations can develop. In the same manner in blocks of late varieties which are alternate bearers the codling moth is practically starved out every other year. Any failure in bearing for whatever cause reduces or prevents the accumulation of a heavy infestation at the end of the season. Sanitation in the orchard and the packing shed, and the prompt removal from the vicinity of the orchard of infested cull fruit after harvest reduce the infestation the succeeding year.

Aside from earliness the varietal combinations affect the problem in other ways. On the other hand varieties which ripen when hatching of worms is at its peak are particularly likely to suffer severe injury. Midsummer varieties which if planted by themselves could not support late generations of worms, when planted in blocks with late varieties ripen at a time to suffer severe damage. Some varieties are particularly susceptible to worm injury for reasons other than time of ripening, because of aroma, thin skin, or other undetermined factors (2, 14). Large blocks of susceptible varieties in an orchard tend to increase the infestation in the orchard as a whole (15).

Moths may migrate in large numbers from a packing shed in which full grown worms can accumulate during harvest, and may intensify the infestation in the crop nearby. Abandoned or partly cared for orchards often are a menace to other nearby orchards and complicate the problem of control.

The temperature in different orchards or in parts of the same orchard may vary because of exposure or altitude. This temperature difference is most easily shown by differences in the time of blossoming of trees of the same variety which may be only a few rows apart. The difference in codling moth infestation may be just as striking to those who observe it.

Control

Control of the codling moth depends first upon a spraying program which is expected to keep the fruit covered with an insecticide during the greater part of the period of hatching of larvae. The purpose of this insecticidal coat is to kill the larvae during the brief interval of time after hatching and before they are able to

enter the fruit. Obviously the protective spray must be on the fruit before hatching begins. The number of spray applications necessary and the time of making them depends upon seasonal history which varies with the region. While a calyx spray and six to eight cover sprays are recommended for northwestern Arkansas, only the calyx spray is required in the vicinity of Winthrop, Maine (29). The variation in requirements for protection by spraying, which may occur within a single state, is indicated by recommendations from the Washington State Experiment Station which outlines four different spraying schedules to suit varying degrees of severity of infestation (41).

The calyx spray, included in all recommendations for codling moth control, is so named because it is applied immediately after the petals fall and before the calyces close. No worms are hatching at this time but the insecticide is applied so that the calyx lobes may be covered before they close and thus have a store of poison ready to kill worms which later may attempt entering at this point.

Cover sprays may be divided into two groups, one of which is intended to protect fruit against larvae of the first generation and the other against larvae of the second and later generations. The first cover spray should be applied just before the earliest worms of the first brood begin hatching, and successive applications should be made to keep the fruit covered throughout this period of hatching. This may involve a succession of as many as three or four applications made at intervals of ten days to two weeks. Perfect coverage at this time is very difficult because of the rapid growth of the fruit, and because of loss of poison due to weathering. While the first generation is not proportionately destructive, its control is important since the later generations originate from it.

The interval between the last cover spray for the first generation, and the first for the second generation depends upon the length of this break in seasonal history between these generations. This is greater in the North than in the South. The first cover spray for the second brood should be finished by the time hatching of the second generation begins. Since there is no interval in hatching between the second and following generations, the spray covering on the fruit should be continuous until near the end of the period of hatching. This requires a succession of applications made at intervals of two to three weeks. The interval between applications is longer than in spring because the area of fruit surface increases more slowly. Spraying is discontinued in the southern apple producing regions as harvest approaches to avoid excessive spray residue. In the northern regions the period of hatching may stop long before harvest, or the infestation may be so light that a short spray schedule is sufficient to control it.

Methods of Timing Spray Applications

The periods during which codling moth larvae hatch vary from season to season and consequently an arbitrary spraying schedule is not practical. In one of the southern apple belts the date of beginning of hatching of larvae of the first generation, which should be the date of finishing the first cover spray, varies from season to season as much as three weeks (15). Under such conditions determining the periods of hatching of the codling moth for each year is advisable. On the other hand, where the codling moth problem is not serious, a fixed spraying schedule based on the average of dates of hatching recorded over a period of years may be satisfactory.

In fixing the time for making the successive spray applications in a given region, the following seasonal history data must be determined each year: (a) the date of beginning hatching, (b) the period of maximum hatching, (c) the end of the hatching period of the first generation, (d) the beginning of hatching of the second generation, (e) the period of heavy hatching of the summer generations, and (f) the general decline and cessation of the hatching of worms for the year.

The methods of securing this seasonal history data vary to suit the region. Where apple production is concentrated in a limited area with uniform conditions, records of several thousand moths reared annually in an insectary by an entomologist may indicate the beginning of their emergence and the range of the seasonal abundance of the species. With this material the beginning of egg deposition and the period of heavy oviposition can be determined. When the first eggs are observed in the insectary, the date when hatching of first brood worms may be expected can be arbitrarily set by adding the average number of days required for incubation under the conditions prevailing. As a check on the insectary records, moths may be collected in bait traps in nearby orchards. Temperature records also serve as a check since the first eggs are almost invariably deposited on the first night when the sunset temperature is above 62° F. after moth emergence begins. If the daily mean temperatures are considered in connection with the number of moths occurring throughout the season the periods of abundance of eggs can be timed more accurately than if the number of moths reared or collected is the only criterion used. Determining the beginning of hatching of the second brood may be based on the time of emergence of the earliest moths without waiting for oviposition since at this time of the year the temperatures are invariably so high that there is no prolonged pre-oviposition period. The average for the combined preoviposition and incubation periods at this time of the year may be added to the first record of emergence in determining the date when the first cover spray for the second brood should be finished.

Where commercial orchards are scattered over a whole state, or where local conditions are variable, bait traps placed in various locations to determine the periods of flight of moths are usually depended on. In this case securing reliable observers may be the first problem. It has also been proposed to determine the earliest emergence of the codling moth by adding the daily mean temperatures in the spring above 50° F. until a total of 550° is reached (6).

Whatever system of prediction is used, it must be based on enough records to represent all conditions. The codling moth itself is variable even if conditions are uniform. In the field moths on warm exposures mature earlier than they would under average conditions. Moths that overwinter in storage cellars may emerge long after the normal spring emergence is passed.

The Insecticide

Arsenate of lead is the insecticide generally depended upon for codling moth control. The advantages of arsenate of lead over other insecticides which it might be possible to use are: (a) the toxicity ranks with the best, (b) the adhesion to fruit and foliage is relatively high, (c) the injury which it may cause to the plants on which it is applied is relatively infrequent, and (d) the cost is relatively low. The importance of the first and fourth advantages are obvious. The second is particularly important when for the control of a pest the protection of the crop must be continuous over a long period of time, requiring a succession of spray applications. When this is required, any reduction in the adhesiveness of the spray covering will necessitate making an increased number of applications. While arsenate of lead causes less injury to apples than most other insecticides used for this purpose, successive applications may produce considerable leaf injury, particularly during seasons of heavy rainfall.

The dosage recommended varies from one to two and a half pounds of arsenate of lead to 50 gallons of spray mixture, depending upon the severity of the infestation. With the higher dosages the hazard of spray injury and the problem of excessive spray residue are increased and the cost is higher.

The effectiveness of the insecticide in codling moth control depends upon the amount deposited and its distribution over the fruit surface. Various materials which are supposed to improve the adhesiveness or spreading quality of the insecticide have been added to arsenate of lead or the spray mixture. Some of these additions are of questionable value. None of the combinations with various colloids have been shown by sufficient experimental evidence to have improved control sufficiently to receive any general recommendation from entomologists. The addition of fish oil or mineral oil have appeared to be consistent in increasing the efficiency of arsenate of lead in codling moth control. The increased efficiency of a combination with mineral oil may be due in part to the action of oil as a contact insecticide since it may kill both eggs and newly hatched larvae. The disadvantages of this combination are that the addition of oil increases the tendency to spray injury on fruit and foliage; it may cause a reduction in the size of the fruit and foliage; bud development may be retarded; and it makes the problem of residue removal more difficult. White summer oils of low viscosity have been found to produce the least injury and to interfere least with residue removal. Spray injury to fruit is more likely to be severe on yellow varieties of apples. The dosage recommended varies from one quart to one gallon in 100 gallons of spray mixture. To reduce the likelihood of damage and the difficulties encountered in removal of residue, it is often recommended that oil be added only to the second and third cover sprays which are applied when the heaviest hatching of the first brood worms occur. In the state of Washington inverted spray mixtures known as "Dynamite" sprays in which the insecticide itself has been wetted by an oil have been developed. By using these inverted sprays it has been possible to build up very high deposits of arsenate of lead (19, 44).

All worms will not be prevented from entering fruit even by a perfect spray covering of arsenate of lead. As stated under the discussion of habits, much of the outer skin and pulp which the worm bites off in making the burrow is thrown into a web which is drawn into the opening as a plug. For this reason a percentage of worms will escape being poisoned. If the infestation is very heavy the amount of fruit injured in spite of spraying may be so large that it gives the impression that the insecticide was not effective. Sometimes worms are killed but not until they have penetrated the skin of the fruit. This perforation may heal but it mars the surface. It is known by growers as a "sting".

Substitutes

Arsenate of lead is not a perfect insecticide since it will not prevent all entries and since it leaves objectionable residues of lead and arsenic upon fruit. For these reasons a diligent search for substitutes has been made for many years, but without complete success.

Calcium arsenate has been most frequently recommended among the various arsenicals as a substitute for arsenate of lead. Its advantage is that it does not add to the lead residue. In the irrigated west cryolite was sometimes used as an arsenate of lead substitute in 2 or 3 applications (22).

Of the non-metalic insecticides which may be substituted for arsenate of lead nicotine has been most used. Nicotine fixed in bentonite in combination with soy bean oil has been reported from Indiana (37) as giving results superior to those secured by the use of arsenate of lead. Nicotine is also used in combination with summer oil. Recent investigations have indicated that xanthone (43) may be substituted for arsenate of lead in some applications. All of these substitutes are effective in part as contact insecticides and for this reason newly hatched worms are less likely to pass through the insecticidal film when fresh. They have the disadvantage, however, of being effective over a shorter period of time than arsenate of lead. They are all relatively expensive.

The obvious advantage of the organic insecticides is that they themselves leave no metalic residue. They may nevertheless complicate the problem of residue removal if a combination with oil is substituted for arsenate of lead in the late cover sprays. A film of oil applied to fruit late in the season covers the residue already deposited by the earlier applications and thus interferes with removal both of arsenic and of lead (4). Furthermore, nicotine combinations cannot be used satisfactorily for codling moth control with Bordeaux mixture nor with lime-sulphur, the fungicides commonly included in the earlier sprays, because these materials may break down the nicotine sulphate so rapidly that its period of effectiveness is very short. Also some combinations produce fruit and foliage injury. Nicotine has an added value in the spray mixture in that it is useful in control of leaf-hoppers which attack apple foliage.

Success in controlling the codling moth is variable. In the apple producing regions where the codling moth has more than two generations a year, its great reproductive capacity makes a failure on any point in the requirements for control likely to result in serious loss. Sometimes, but not often, this loss may be charged to the insecticide used but more frequently it is because of laxity in regard to the time and number of spray applications necessary. Still more frequently haste in making spray applications with a consequent lack of thoroughness is the source of failure. Any spraying equipment which tends to hasten the spraying operation unduly is likely to lead to this error. Writing in Washington, Marshall and Groves (19) stated, "The majority of growers fail to appreciate either the implication or importance of thoroughness". This statement has a much wider application than to fruit growers but few insect pests have a high enough reproductive capacity to take as full advantage of any laxity in control measures.

The cost of spraying should not be charged entirely to codling moth control. The succession of spray applications controls a number of leaf feeders and reduces injury by other pests like the curculios and fruit flies that attack the fruit directly. Most of the applications are made in combination with fungicides, resulting in a lower cost for labor than if each material were applied separately.

Spray residue may be considered a part of the codling moth problem. Arsenic can be removed quite easily provided no sticker has been used in the spray mixture. Lead residue is harder to remove. Both lead and arsenic residue, even when applied with oil, can be removed by using a solution of one and a fourth to one and a half per cent hydrochloric acid, heated to a temperature of 105° to 110° F. in which the apples are exposed 30 seconds in an under brush machine, or 150 seconds in a flotation washer. An increase of acid, or of time of exposure, or of temperature, may injure the storage life of the fruit. The use of a degumming agent in the acid bath which removes the oil and natural wax may replace the necessity for as high a temperature as indicated. Spray residue removal under these conditions presents a difficult problem and any deviation from the recommended procedure is likely to cause injury to fruit.

Supplementary Measures

Since a percentage of worms will actually burrow into fruit through an insecticidal coating, spraying alone will not prevent injury. If the initial infestation in an orchard from the previous season is unusually large, severe loss may occur even in spite of the best procedure in spraying. Under such conditions supplementary measures of control may be necessary. The most effective supplemental measure is destroying the larvae hibernating under the bark by scraping the bark from the tree before the spring emergence and trapping the successive generations under bands. Prompt removal after harvest of culls which are sometimes held for sale in bins or piles in an orchard, may prevent worms partly grown from completing their development in the

orchard after harvest and spinning cocoons where the fruit is held. Evidence of the value of orchard sanitation as a supplementary measure is shown by a large scale experiment in a sprayed orchard in Indiana in which the infestation was reduced 57.1 per cent in the part in which sanitary measures were applied (36).

SUMMARY

Prevention of loss to the apple crop because of wormy fruit is the most important problem in apple production. The worm or codling moth larva burrows into the fruit, almost immediately after hatching, where it feeds until fully grown. Thus after entering the fruit it is protected from direct control. Control depends primarily upon spraying with an insecticide which will kill the larvae during the brief period they are on the surface of the fruit. In some regions the hatching period may continue for months, and where this is true a succession of spray applications are necessary to afford continuous protection. The number of applications necessary varies widely in the different apple producing regions of the United States depending largely upon the duration of the hatching period and the severity of the problem. In Maine the damage is relatively light even if uncontrolled, and only one application is necessary. Along the southern border of apple production the pest if not controlled may destroy the entire crop. Control may require as many as eight sprays and the requirements for careful attention to details are more exacting. The problem is so difficult because the long growing season of the southern apple regions and the relatively high temperatures may make possible the development of a succession of as many as four generations in a year, while the high temperature also favors high fecundity.

The codling moth hibernates as a full grown larva most commonly under bark of the apple trees on which they have developed. These larvae transform to pupa and ultimately to the moths which deposit eggs from which the first generation of worms hatch. The hatching period of the first generation is usually distinct from the hatching period of the second and following generations. Where the late generations occur they invariably overlap so that hatching is continuous from the beginning of the second generation until the end of the season. The number of spray applications which are expected to cover fruit during the hatching period depends upon the length of the periods and upon the intensity of the infestation. These spray applications are known as "cover sprays". In addition to cover sprays a single application is made before hatching begins, in the interval between the falling of the petals and the closing of the calyces. The application, called the calyx spray, is made because a large percentage of worms try to enter fruit at the calyx end. The method of determining when the cover sprays should be applied may depend upon rearing large numbers of moths in insectaries or upon bait trap records. The accuracy with which these sprays are timed may be improved by taking the prevailing temperature into consideration.

Arsenate of lead is the insecticide generally depended upon for direct control of the codling moth. Extensive search has been made to find a substitute which will not leave an objectionable residue on the fruit and which will be more efficient. Although sometimes substitutes have been recommended for a part of the applications up to the present time none has been found which will replace it in general usefulness or at a comparable cost.

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CHAPTER XV

SPRAYING SCHEDULES FOR DESTROYING ADULTS OF FRUIT-INFESTING LARVAE

The control of curculionids and trypetids which attack fruit, like that of the eucosmids, also depends upon a spraying schedule. However, the stage at which control is directed differs. The larvae of fruit infesting weevils and fruit flies actually hatch within the fruit itself, since the eggs are inserted under the skin by the adults. Therefore, they cannot be killed by an insecticide upon the surface of the fruit, like those which enter fruit after hatching.

The head of weevils is prolonged into the shape of a beak. With this prolonged head, the characteristic species feed upon the tender tissues within the fruit or plant part attacked, and deposit their eggs in a cavity formed by feeding. Thus the larvae are hatched within their fruit hosts and do not have to enter from the outside. Normally they do not appear outside the fruits at least until their feeding period is over, and hence are not accessible to control by spraying. The adults, however, do feed sparingly upon the surfaces of plants attacked.

The female fruit flies insert their eggs under the skin of their host fruit. The adults do not feed upon the fruit tissue itself, but pick up particles that happen to be upon the surface of fruit or foliage, and for this reason control of trypetids, like that of curculionids, can be directed against the adults.

THE PLUM CURCULIO

There are a large number of curculios or weevils* in the United States that attack fruits or fruiting parts of plants. Perhaps the best known of these are the plum curculio**, a pest of stone and pomaceous fruits, and the cotton boll weevil*** which attacks the buds, or "squares", and bolls of cotton. Related to the boll weevil is the apple curculio**** which attacks the fruit of the apple and causes injury which is sometimes confused with that of the plum curculio.

The plum curculio is the most important pest of stone fruits within the United States and is also an important pest of the apple. Although its favored host is the plum, its injury to the peach crop is of greater monetary importance because of the greater acreage and value of the latter crop. It has been estimated that within its range, it causes a reduction in the yield of plums and prunes in excess of 50 per cent, in the yield of peaches in excess of 30 per cent, and in the yield of apples in excess of 10 per cent (6). In the Georgia peach belt during the outbreak of 1920 only a small proportion of the late peaches were marketable (8). All the loss cannot be charged to the curculio because the brown rot disease is associated with curculio injury. It has been stated that in Georgia while at least 50 per cent of the fruit which is unprotected by insecticides may be infested by curculio larvae, the injury has been held to less than two per cent in well cared for orchards (7). On apples it is ranked as the most important insect pest in Massachusetts, and next to the codling moth as a pest of this fruit within its entire range. No estimates of percentage of injury are available for its other hosts. Nectarines and apricots are preferred by curculios to peaches. Cherries are occasionally injured, and sweet cherries are preferred to sour varieties. Injury on pears and quince occurs but it is not important.

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*Family Curculionidae.

**Conotrachelus nenuphar (Hrbst.)

***Anthonomus grandis Boh.

****Tachypterellus quadrigibbus Say.

The adult is small, stout, rough surfaced snout beetle about one-fifth of an inch long. In color it is dark brown mottled with gray. On each elytron are two humps. The larva is a stout, footless grub about three-eighths of an inch long and whitish in color.

The plum curculio is a native of North America where its natural host is the wild plum. It is not known to occur west of the Rocky Mountains.

Type of Injury

Both the adult curculio and the larva injure fruit. The adults make a circular opening in the skin of the fruit and then eat out a pit under it about as deep as the length of its snout. When preparing for oviposition the female makes a slit under the skin. After depositing an egg in the cavity she cuts a crescent shaped slit in front of the egg puncture which she extends obliquely under the egg. The crescent shaped cut insures that the egg is protected at least for a short time from pressure from growing cells. Egg or feeding punctures may heal over on apples leaving russeted scars the shape of the puncture. Such fruits are usually distorted.

The injury by larvae is caused by feeding within the fruit. Upon hatching larvae usually burrow to the seed cavity. As a result of this activity most infested stone fruits, except cherries, drop to the ground. If the fruit does not drop the egg or young larva may be crushed by the rapidly growing tissues. Among its important hosts the larval survival is highest in plums and lowest in apples. Very few larvae reach maturity in apples which hang on the tree except in very early varieties. This probably accounts in part for the fact that at least in northwestern Arkansas curculio injury is slight in apple orchards that have no peaches or plums near them, although the infestation may be quite severe in apples where stone fruits are adjacent. Likewise injury to sour cherries isolated from other stone fruits is rare.

Life History

The life cycle from egg to adult in Georgia requires an average of over 52 days for the first generation and about 5 days less for the second generation which occurs in midsummer (8). The egg stage varies from 2 to 12 days. The larval feeding period in peaches averages 21.5 days in April and 12.4 days in July. A longer feeding period is required for larvae in apples. When the larva is full grown it leaves the fruit and forms a pupal cell in the soil, usually within the top two inches. In this cell it transforms to the pupal stage and later to the adult. The weevil remains in the cell until it hardens. This entire period in the soil averages from 30 to over 34 days in summer in Georgia.

The time required for development of the immature stages in apples in New York averages 7 days for the egg stages, 16 days for the larval feeding period, and 30 days in the pupal cell in the soil (4).

The maximum possible reproductive capacity of the plum curculio is apparently greater than that of the codling moth, for as many as 516 eggs are reported as having been deposited by a single female (8). The daily egg deposition is much less however, for the oviposition period may be extended over two months. According to records in Georgia (8), an average of only 65 eggs were deposited by over wintered curculios, and 40 by curculios of the first generation.

Seasonal History

The plum curculio passes winter as an adult in leaves and trash in and around orchards. Leaves are the preferred cover, although fence rows, woodlands adjacent to orchards and a cover of grass also furnish satisfactory situations for hibernation

(8). The beetles usually hibernate outside of orchards as is shown by the fact that the heaviest infestations in orchards are on the outer margins. They may fly a half mile to hibernation quarters (10). Some beetles do hibernate under the trees in the orchard and in the ground.

A mean temperature of 55° to 60° F. is required to cause beetles in hibernation to become active, and when 60° F. occurs for several days in succession the beetles in hibernation tend to come out. In the southern peach belts the period of heavy emergence is generally coincident with peach blooming (8). In the northern peach belts the time of emergence in relation to the development of peaches is a little later. The period of emergence is completed in about five weeks.

Curculios begin oviposition in the little peaches as soon as the calyces fall. The oviposition period of overwintered beetles may extend over a period of two months. Oviposition by the overwintered generation is practically completed by the time adults of the first generation emerge from the soil.

Only one generation of plum curculios occurs each year in most of the northern states. In most seasons there is a partial second generation in the southern peach belts. This partial second generation occurs at times in Arkansas and sometimes as far north as Virginia and southern Illinois (2,3). A trace of a third generation occurs in Georgia during some years (8). Curculio grubs in peaches at harvest are usually representatives of the second generation.

The abundance of curculios throughout the season may be determined by jarring the trees. The efficiency of this practice is based on the tendency of the beetles to drop from foliage when disturbed, at least if the temperature is low. A sheet held under the trees when they are jarred will catch the falling curculios. When the temperature is high they take refuge in flight and for this reason jarring is usually done in the morning. If jarring is practiced in an orchard at regular intervals throughout the season and the collected beetles scored, a dependable outline of the seasonal occurrence can be secured. Jarring has been recommended as a supplementary control practice.

Control

Insecticidal control of the curculio must be directed at the adult, because the egg is deposited beneath the skin of the fruit and the larva is not accessible to attack. The period during which the adults of the overwintered generation emerge from hibernation and begin feeding is the critical period during which the curculios should be destroyed. On apples in the northeastern states where the species is "single-brooded" this period covers about five weeks. In the southern states where two generations occur, chief attention is given also to the overwintered generation, although one spray application may be made before harvest to destroy the newly emerged adults of the first generation. The value of spraying the foliage of peaches after the fruit is harvested to destroy curculios before they go into hibernation has also been given experimental trial but is not now recommended. The problem of curculio control on peaches is complicated by the susceptibility of peach foliage and fruit to arsenical injury.

Recommendations for insecticidal control usually follow an arbitrary schedule which is not shifted from year to year as are recommendations for the control of the codling moth. As for instance, for controlling the curculio in apples in New York three applications are recommended, the first when the petals fall, a second 7 to 10 days later, and the third 10 to 14 days after the second (4). This is expected to give protection over a period of about five weeks, or the period of emergence from hibernation. In Massachusetts, however, seasonal variation is recognized and it is

recommended that spray applications be concentrated in the early part of the critical period which occurs with the first warm weather after apples blossom when the temperatures reach 75° F. (11).

When spray applications on apples are made for curculio control, one and a half pounds of arsenate of lead in 50 gallons of spray mixture are recommended. In apple regions where the codling moth presents the dominating apple insect problem, it is expected that spray applications made for its control will keep the curculio in check.

The timing of control on peaches is similar. In Georgia (9) it is recommended that the first application be made when 75 per cent of the petals have fallen, and the second application is when the calyces, or "shucks", are shed. This usually occurs about 10 days after petal fall. On account of the somewhat later emergence of curculios from hibernation in the North, the first application is usually made when the calyces are shed, and the second about two weeks later. In the South a third application may be made for the protection of late varieties about one month before the fruit ripens.

The spray mixture applied on peaches should consist of one pound of arsenate of lead in 50 gallons of water either with three pounds of stone lime or with a fungicide. When the insecticide is applied in dust the amount of arsenate of lead in the dust mixture should be five per cent. The advantage of spraying over dusting is most noticeable when the infestation is heavy.

The control of the curculio is more difficult on plums than on peaches. The same spray schedule may be followed and the dosage of arsenate of lead should be one and a half pounds in 50 gallons of spray mixture. When infestations are very severe additional spray applications may be necessary.

Control of the curculio by insecticides may be supplemented by cultivation of the orchard when the pupae are in the soil, and by sanitation which would involve destruction of fallen fruit, and a clean-up of places favorable for hibernation, and sometimes by jarring trees.

THE APPLE MAGGOT

The apple maggot* is probably the best known representative of the fruit flies in the family Trypetidae which injures fruit in the United States. The cherry fruit flies are among its better known relatives in this country, while the Mediterranean fruit fly may have the most nearly world-wide reputation of destructiveness. The apple maggot is a major pest of the apple in the northeastern states and the adjoining provinces of Canada where in some orchards at least it may infest 100 per cent of the crop. A biological strain of this species is also a first rate pest of blueberries in the same range. It is actually much more widely distributed since it is known to occur as far south as Georgia and Arkansas, and as far west as Kansas and the Dakotas (15). It is not important, however, in the more southern and western part of its range. It is possible that the extended spraying schedule for codling moth control in this part of the country may have reduced its importance as a pest.

The apple maggot is a pest of American origin. The fruit of the hawthorn may have been its native host. In addition to this host and apples and blueberries, the species has been reared from pears, plums, cherries, bunchberries, chokeberries, service berries, and wintergreen. Among apples, early varieties are preferred (13).

The injury to the larger fruits is caused by the larvae burrowing through the pulp and leaving a trail of rotten tissue behind. This type of injury is responsible for the name "railroad" worm by which it was formerly known. Fruits infested with

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*Rhagoletis pomonella (Walsh).

several larvae may be riddled with tunnels. The injury to blueberries is of importance in still another way. Infested fruits must be sorted out from berries used by canners, or the canned product is rendered unfit for sale. This results in increased cost of sorting and processing berries in addition to shrinkage from injured berries.

Life History and Seasonal History

Fruit flies can often be recognized by dark bands on the wings. The adult of the apple maggot is slightly smaller than the house fly. The wings are marked by four dark confluent bands. The whitish maggot is about a fourth of an inch long when full grown.

The apple maggot passes winter as a pupa in the soil, usually within an inch of the surface. Emergence in the New England States and New York begins in early summer and continues for a period of about five weeks (13,17). The adult fly feeds for about two weeks or more before beginning to deposit eggs. The eggs are inserted under the skin of the fruit attacked in groups of four or five. As many as 46 egg punctures have been found in a single fruit (17). Several hundred eggs may be deposited during the life of a single fly. The extent to which the adults migrate from tree to tree is shown by the fact that marked specimens have been recovered 233 yards from the point of release (18).

The larvae develop rapidly in early apples and become full grown in about two weeks. In late green apples which hang on the tree the period of larval development may be prolonged to cover several months. In late apples the larval mortality is very high, particularly if the fruit does not fall from the tree (15).

After becoming fully grown the larvae leave the fruit and enter the soil where they pupate. A percentage of those that developed in early fruits transform and give rise to a second generation the same year. The majority, however, emerge the following year. Some pupae even remain in the soil until a second summer and a few have a rest period even longer than two years. In studies of blueberry maggots in Maine of those which pupated, about 75 per cent emerged the next year, about 19 percent emerged the second summer after pupation, about 5 per cent emerged the third summer, and .54 per cent emerged the fourth summer (16). This tendency of some individuals of the species to have a prolonged pupal period is of great importance in the survival of the species in carrying it through periods of crop failure.

Control

Measures for control of the apple maggot by spraying must be directed against the adult, since the larva, like that of the curculios, hatches and feeds within the fruit and is not accessible to insecticidal control. The adult fly is not directly injurious. It does not feed upon fruit but picks up particles through its mouth parts which are like those of the housefly. It can be killed quite readily with arsenical insecticides. Its long preoviposition period of two weeks or more is the weakness in its life cycle and if it can be destroyed during that time the injury by the maggots may be prevented.

A dosage of 1½ pounds of arsenate of lead in 50 gallons of spray mixture is recommended for control of the apple maggot on apples (13). Two applications should be made. The first should be applied after the beginning of emergence of the flies, and the second about two weeks later. With these two applications, the insecticide may be expected to remain on foliage and fruit throughout the entire period of emergence of flies. Since the flies are likely to rest on foliage of any plant near the place of their emergence, spraying of shrubbery adjacent to orchards is sometimes advisable. Control by spraying is less effective where the host trees are scattered

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or are interplanted with other trees, or on city properties where flies can migrate in from nearby unsprayed trees (13).

A number of substitutes for arsenate of lead have been given experimental trial but none have been found satisfactory. The addition of a sweet material, such as molasses, to the arsenate of lead spray has been recommended, but later was found not to increase the effectiveness of the control (12). Using spraying machines in blueberry fields is considered impractical. For the protection of this crop dusting is recommended using six to seven pounds of calcium arsenate to the acre (16). The principle of timing is essentially the same as for spraying apples.

SUMMARY

The plum curculio injures fruit of stone and pome fruits both in the adult and larval stages. The apple maggot injures apples and blue berries only in the larval stage. Although these insects belong to different orders, their control is similar, since in both instances it must be directed against the adults. The eggs are placed within the host fruits and the entire larval feeding period is passed where the larva is not susceptible to direct control.

The aim of control measures is to destroy the adult after it comes out of hibernation and before egg deposition begins. The curculio begins to emerge from hibernation in early spring, the adult of the apple maggot in early summer. In each case the emergence from hibernation extends for a period of over a month, and a succession of at least two spray applications is necessary to give reasonable protection during the period of abundance. On peaches in the South a single spray application is recommended for the control of the newly transformed adults of the first generation. When these pests occur on apples which receive a succession of spray applications of arsenate of lead for control of the codling moth no additional measures may be necessary. The abundance of both species is affected by conditions outside the orchard. The plum curculio hibernates outside of orchards and its number may be greatly increased if wild plums in which its breeding is uncontrolled are in the vicinity. Shrubs and shade trees adjacent to apple trees may make control of the apple maggot more difficult since during the preoviposition period many of the adult flies may rest on this foliage instead of on that of its sprayed hosts.

The insecticide used for both insects is arsenate of lead. The number of applications which may be made on peaches is limited because of the susceptibility of peach foliage and fruit to arsenical burning.

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CHAPTER XVI

THE COTTON BOLL WEEVIL

The cotton boll weevil*, like the plum curculio, is accessible to control by insecticides only in the adult stage. The boll weevil has a shorter life cycle than the plum curculio and more generations a year, consequently, the period during which its host is subject to attack is much more extended. It is also much more erratic in its occurrence from season to season and from region to region. For these reasons a regular, annual schedule of insecticidal applications is not depended on.

The cotton boll weevil is the most important pest of cotton in the United States and probably the most important crop pest in this country. For a period of four years prior to 1920, it was estimated to have caused an average loss of 300 millions of dollars annually (7). During other years the injury has been considered about negligible. When conditions are favorable for development, weevil outbreaks build up and spread with remarkable rapidity. Weevil injury is more acute in the southern part of the cotton belt than in the northern part. The invasion of the South by the weevil was responsible for the reduction of acreage in cotton in the Gulf States during the decade following its first appearance and for the increase in acreage farther north, as in northeastern Arkansas and western Texas during the same period.

The extent of damage caused by the boll weevil has received more attention than that of any other crop pest. For a number of years estimates of these losses for each state were published in the yearbook of the Department of Agriculture. For the state of Georgia during the years 1921, 1922, and 1923 the losses were estimated at 45.1, 44.3, and 36.6 per cent respectively. The yield of lint cotton to the acre in Georgia, during these years, was respectively 53.6, 48.7, and 57.9 per cent less than the average for the ten years immediately before the advent of the boll weevil in that state.

The extent to which the boll weevil injures cotton may be shown, also, by the increase of cotton yield in years when the boll weevil is absent. A season of extreme drought will reduce the boll weevil to a negligible factor, but may also injure the cotton. Such conditions may result in low yields. The first favorable growing season which follows, however, will produce a high yield, since at least one summer is necessary for the boll weevil to again become abundant enough to cause injury.

Weevil damage varies from year to year. As for instance, in Arkansas during the seasons of 1921, 1922, and 1923, it was at some time abundant and reduced cotton yields in practically all cotton fields of the state. During that period its control was regarded by many as the most important agricultural problem in Arkansas. In contrast to this the species was of negligible importance in 1930, since it was practically absent from the greater part of the state. During the intervening years, from 1924 to 1929, the boll weevil was destructive in some parts of the state, although the extent of damage varied greatly. It reappeared late in 1931, and in 1932 it was again destructive over the whole state except the northeastern part. From 1933 until 1939 there were no statewide losses, although outbreaks threatened in the southwestern part both in 1938 and 1939, but were checked each season by a serious drought. In 1940 it was again destructive over most of the state.

The boll weevil problem may also vary in different parts of a state and in different localities. Cotton in some localities and on some farms suffers fairly regular annual damage, while in others nearby it escapes injury except in occasional

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*Anthonomus grandis Boh.; order Coleoptera, family Curculionidae.

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years. For this reason the problem is often a local one, and measures which should be taken for its control may vary with the farm and the region, as well as with the season.

As already indicated, the weevil problem is more severe in the southern part of the cotton belt, particularly in the states along the Gulf Coast and the southern part of the Atlantic Seaboard than in the more northern or western cotton states. The reasons for this are: a long growing season, relatively high summer rainfall, the occurrence of Spanish moss, and in some situations the occurrence of volunteer cotton. As a result, the infestation is more general and tends to be more difficult to control than in the more northern states. In the western part of the cotton belt, west Texas and western Oklahoma, the number of boll weevils is generally reduced by dry summers.

If weevil injury were evenly distributed, the resultant crop loss would be less significant and in some seasons might be overlooked. It is the unequal injury that makes the financial loss acute. When the average loss is great enough to affect prices, those growers who escape injury, either because of favorable location or by controlling the weevil, may be actually benefited. At the same time the losses suffered by others may be ruinous.

Origin and Distribution

The boll weevil is a native of the plateau of Mexico or Central America. It now inhabits the entire Cotton Belt of the United States frm West Texas eastward. It crossed the Rio Grande near Brownsville and entered Texas in 1892. By 1907 it had crossed the Mississippi river. In 1915 it invaded Georgia. It spread eastward and northward until in 1921 the entire Cotton Belt had been covered (7).

Hosts and Manner of Injury

The only host of the boll weevil in the United States upon which it is known to develop from egg to egg is cotton. Eggs are rarely deposited in the fruits of other malvaceous plants, okra and hibiscus (7), and three adults were reported having been reared from the latter. Even on cotton the boll weevil is dependent upon the presence of squares or small bolls for reproduction. While larvae can develop in large bolls, females will not deposit eggs unless squares or small bolls are available for food. High fecundity is possible only from weevils which have fed on squares (11).

Injury to the cotton crop is initiated by the adult weevil by feeding upon or depositing eggs within squares or flower buds and bolls. The squares and small bolls which are punctured stop developing and ultimately drop from the plants. As a first indication of such injury the bracts around the square flare and turn yellow, and when this occurs they are readily noted. The rapidity with which flaring and shedding of squares takes place depends upon the weather at the time, and the amount of fruit on the plant. If an egg is deposited in a large boll, the resulting larva may destroy only the lock in which it is placed.

Life History

All the immature stages of the boll weevil are spent within the squares or bolls of cotton. The egg, which is deposited in a cavity made for it by the parent weevil in a square or boll, is about one-thirtieth of an inch long, elliptical, and pearly white in color. The whitish legless grub, or larva, is well known, and is the stage most commonly found in squares or bolls. The white and delicate pupa, the stage into which the grub passes before transforming to the adult, is also found within the square.

The time required for complete development of weevils in squares under field conditions in summer will average around 17 days. The female weevils may feed 7 or 8 days more before beginning to lay eggs, which makes a total of about 25 days required for the completion of the life cycle. Under the most favorable conditions of temperature and moisture the development may be even more rapid, and the life cycle from egg to egg may be completed in 16 days. Individual weevils may deposit over 30 eggs a day (11) and as many as 440 eggs during their entire life (4). Rapidity of development is also closely correlated with an abundance of squares.

Hibernation

In spite of its tremendous capacity for multiplication the boll weevil receives an annual setback each year between crops, and of the myriads of weevils which go into hibernation in the fall usually not one per cent are present in cotton fields the next year when cotton begins forming squares. The number of weevils present in cotton fields when the first squares are formed often determines the possibility of destructiveness of the boll weevil during that season. That number depends in part upon the percentage which successfully pass winter and the long period in spring before cotton begins fruiting. In the northern cotton states this percentage of survival is favored by the availability of suitable cover for hibernation and also by moderate winter temperature. Obviously the percentage of winter survival is much higher in the southern part of the Cotton Belt than in the northern part. The number of weevils present at the beginning of a season also depends in part upon the abundance of weevils during the fall of the previous season. Thus a year in which severe injury occurs is invariably preceded by one which has been favorable particularly in the last part of the season for the development of weevils.

Boll weevils pass winter in trash or dead grass in or around fields. Situations such as high ditch banks, well drained woodlands overgrown with grass or weeds, brush in fence rows, grass-grown terraces and turn alleys cutting across fields, and vegetation around stumps in fields are frequent sources of infestation. In the states on the Gulf Coast they may hibernate successfully in Spanish moss, and for this reason in those states may be most abundant around swamps. In the part of the cotton belt north of the range of Spanish moss, they do not usually pass winter where land is subject to standing water in winter.

Progress of Infestation

Weevil activity starts with the beginning of warm weather, when weevils emerge from hibernation and fly to the nearest cotton. This emergence covers an extended period, and doubtless the great majority of weevils coming out of hibernation die before the cotton plants begin setting fruit (5). The first evidence of injury by weevils appears soon after squares are available for food. The areas infested by overwintered weevils in the northern part of its range are usually small and are near situations particularly favorable for hibernation. Except in 1932 and 1941, the cotton acreage in Arkansas infested by the spring brood has never exceeded five per cent for the total in the state. On account of the small amount of cotton infested, this brood does damage in relatively few fields. It is of greatest importance as a source of subsequent infestations.

When the infestations are small, it is difficult to find them until they are marked by flared and fallen squares. Early in the season injured squares may not flare until a week or more after they are punctured, and unless the infestation is heavy are not much in evidence until the greatest activity of weevils of the spring brood is past. Most of the weevils of this brood die within two weeks after cotton begins setting squares, and following this there may be a period of very little injury to cotton. In the Gulf States this break between generations does not occur regularly.

Weevil activity is renewed with apparent suddenness as adults of the first brood mature. This is the beginning of the second period of infestation. The first generation usually requires more time for development than those in midsummer and it usually appears about 30 days after the first setting of squares. Upon leaving the squares in which they have developed, the full grown weevils feed on the nearest plant and at first migrate but little. When the weevils have attained sexual maturity, however, they begin to migrate, destroying cotton as they go. As a rule this migration is direct, that is to the nearest cotton, and is not characterized by long flights into other parts of the field. If the area infested by the overwintered brood has been marked, the grower can know in advance the cotton which will be infested next, and can easily find the first feeding punctures in squares before migration begins. The presence of large numbers of pupae in fallen squares indicates when a new generation of weevils is about to appear. This brood of weevils is much more numerous and consequently much more destructive than the previous one, and during the period of its activity usually the first heavy damage to cotton occurs. Much cotton, however, may still be free from injury at this time. Usually it is in fields attacked during this period of infestation that the most serious damage is done.

No distinct break occurs, as a rule, between the second and third periods of infestation, although the weevil injury may decline in the latter part of the interval between them. The beginning of the third period of infestation is marked, however, by a sudden increase and rapid spread of weevils in the cotton fields. In years when heavy weevil injury occurs the third period of infestation begins around 50 to 60 days after the beginning of setting of cotton squares. Weevils are now very numerous and are forced to search widely for food. At first they may spread directly across a cotton field like weevils of the previous generation, but as fields become totally infested they take recourse to flight. This is known as the late summer dispersion. While the progress of infestation as described may be considered as typical of an average season, the rate of spread varies greatly from year to year (9).

Because of the large area affected, the total weevil injury following the third period of infestation is usually greater than that caused earlier in the season, although cotton which is not attacked until that time may have set a fair crop of bolls. Where cotton fields are not infested until after September 1, the injury is still less. Late in the season after all cotton fields become infested, weevils migrate from one field to another and frequently fly long distances. Activity of the weevils at this time of the year is of relatively little importance except for its bearing on the number of weevils which may go into hibernation.

Factors Favoring Abundance

The intensity of weevil infestation during any year depends largely upon the weather during the summer months of that year, and during the latter part of the preceding growing season and winter. Unless weather conditions favorable to the boll weevil occur, outbreaks do not materialize.

A warm fall combined with abundant rainfall stimulates a production of an abundance of squares and may make possible a great multiplication of weevils just before hibernation. Such conditions do not affect the crop of that season, but are essential if an outbreak occurs early in the season of the succeeding year. The importance of successful hibernation has already been discussed.

Summer weather is favorable to a weevil outbreak when a moderately high temperature is combined with a high relative humidity (5). On the other hand, excessively hot and dry weather may check or destroy an incipient outbreak. Weevil infestations in cotton growing on heavy soils, where foliage is luxuriant, are less affected by unfavorable weather than fields on light sandy soils. Weevil grubs in squares develop more rapidly than those in bolls, but the immature stages in bolls are more resistant to unfavorable conditions than those in squares.

At a high mean temperature, 82° to 84° F., such as prevailed in central and southeastern Arkansas in 1923, the development of the weevil is very rapid, and makes possible a rapid succession of generations. Also the rate of reproduction is stimulated by high temperature. As for instance, at a mean temperature of 84° F., an average of over 15 eggs may be deposited daily by each female weevil, or about seven times as many as the average daily egg deposition at a mean temperature around 70° F. Under optimum conditions female weevils will deposit an average of 300 eggs. Optimum conditions include a mean temperature of about 82° F. and an abundance of squares for food. Weevils which feed on bolls do not deposit many eggs and if only old bolls are available for food, oviposition practically ceases. An abundance of squares implies rapid growth and an abundance of rainfall. Oviposition is high at temperatures above 82°. In fact daily oviposition may be more rapid up to about 90° F. but above 82° F. conditions become unfavorable for the development of grubs in squares. During periods of extreme drought almost no weevils can develop in squares. The largest percentage of grubs in squares mature at temperatures between 76° and 82° F., and when the relative humidity is high (11).

Control

In the program of control of the boll weevil the destruction of the weevils in hibernation, relatively early production, and where feasible the destruction of cotton plants after picking the crop to prevent continued breeding in the fall, all are important. These indirect measures alone may prevent appreciable loss. They may be supplemental measures which make direct control easier or more effective.

Dusting with calcium arsenate has been found to be the best means of protecting cotton after weevils have entered a field. Calcium arsenate is the cheapest of the arsenical poisons and is the best suited for application in dust form. Much of the weevil mortality is a result of weevils picking up loose particles of dust while crawling over the plants (13). Dusting experiments carried on in most of the cotton producing states by entomologists from the state experiment stations and from the Federal Bureau of Entomology have demonstrated the effectiveness of this method of control (8, 12, 15). As for instance, dusting experiments were conducted in Arkansas during the period from 1923 to 1926 and again in 1932 in locations representing all parts of the state. For all plots dusted during the three years before the late summer dispersal began, the increase in yield of seed cotton over the adjacent checks averaged approximately 120 per cent (10, 12).

Notwithstanding the efficiency of dusting with calcium arsenate in control of the boll weevil, it has not been used with uniform success by cotton growers. Failure to make applications at the right time and to recognize the limits of the early infestations are probably the most frequent causes of unsatisfactory results from dusting. It was noted in 1922 and 1923 that many planters began dusting cotton after the squares punctured by overwintered weevils were turning yellow and falling from the plants. Usually this was in evidence after most of the overwintered weevils had died and before the first brood had matured. Dusting whole fields when only spots are infested is wasteful as well as inefficient (9, 10). Dusting is also unprofitable if it is undertaken on an extensive scale under conditions when serious injury does not occur.

The methods of timing dust applications should vary to suit local conditions. As a rule in Arkansas "spot dusting" has been found to be the most effective as well as the most economical. It checks small infestations of weevils and also prevents or delays their spread. Success in "spot dusting" depends upon locating and dusting the early infested spots before weevil migrations begin. Small areas in cotton fields infested by overwintering weevils are usually difficult to locate until squares begin to flare and fall. This is usually too late for dusting to be most effective,

since it is in the interval between the activity of the overwintering brood and the first brood. The next infestations, however, can be expected to arise in the same places after another generation has time to develop. By marking these spots, the earliest feeding on squares by weevils of the first generation can be noted and dust applications can be made, not only before weevils have a chance to migrate but before they have begun to reproduce. In the same way the beginning of the next period of activity can be anticipated and the parts of the field from which it will spread can be located (9, 10). "Spot dusting" is most satisfactory during seasons when the early infestations are widely separated which usually follow severe winters. It is also useful where suitable hibernating quarters are scarce. It is better suited to the northern part of the Cotton Belt than to the southern part.

In fields where there are scattered infestations in parts of nearly every acre, locating each infested area and treating it separately is not practical. Under such conditions whole fields or "cuts" should be dusted. Dusting should be started when injury actually begins, or when 10 to 15 per cent of the squares show fresh punctures (8, 10). This method of timing applications is usually recommended in the southern part of the cotton belt. During some years, like 1941, there was heavy widespread population of overwintered weevils in many parts of the South at the time cotton began forming squares. Under such conditions early applications were of value.

In 15 years of dusting experiments carried on by the United States Bureau of Entomology and Plant Quarantine it was shown that the gains from dusting were greatest during years when the infestation in the untreated plots increased rapidly. In years when the infestation increased slowly, the increases in yield resulting from dusting may hardly have paid the expenses of the operations (15). In 1924 the average number of infested squares on untreated plots during any week up to the first of August did not exceed 18.5 per cent. During that year the average gain from dusting was only 10 pounds of seed cotton to the acre or 1.1 per cent. In 1926 the average number of infested squares on untreated plots was more than 30 per cent during six weeks. During that year the average gain from dusting was 742 pounds of seed cotton to the acre, or 68.3 per cent.

Weevil control is usually more profitable on fertile land which produces a luxuriant growth of cotton than on poor land (10, 14). Furthermore, weevil control is more likely to be necessary on fertile land. On the light sandy soils where the plant growth tends to be small, weevil infestations are readily checked by periods of summer drought and heat.

Dust applications made in early summer where the first infestations occur result in the greatest financial returns. Where the losses are earliest it may naturally be expected that if the pest is uncontrolled, the losses will be greatest and logically it is most important to control the weevil under these conditions. Furthermore before the late summer dispersion begins it is usually necessary to destroy only those weevils which have matured within a field, and results are not complicated by frequent flights into a field from the outside. Dusting in early summer is also of more value than late dusting, since it should not only protect cotton through the period of heaviest fruiting, but also delay the spread of weevils to adjacent cotton. A comparison of the average gain in yield of seed cotton to the acre in plots with early, intermediate and late boll weevil infestations, in experiments in Louisiana, is shown in table 5.

Table 5. Gains from boll weevil control in Madison Parish, Louisiana. 1920. (Adapted from Young. 15)

Period of first infestation	Seed cotton produced to the acre		Increase in yield	
	Undusted plots	Dusted plots	Pounds	Per Cent
Early	740	1,065	325	43.9
Intermediate	834	1,122	288	34.5
Late	1,042	1,222	180	17.3

After the late summer dispersion first begins the profits from dusting decline rapidly. Areas dusted at this time may act as a temporary barrier to migrating weevils which are spreading directly across a field from row to row. Only temporary protection, however, can be expected at this time. Gains from dust applications are difficult to see when there is an almost daily flight of weevils into a field. Even squares which are temporarily saved by dusting may be destroyed later. Direct losses due to driving dusting machinery through fields of cotton heavily loaded with bolls is also a consideration.

Dust should be applied at the rate of five to seven pounds to the acre. In early summer a series of two to four applications made at intervals of four or five days will usually bring the weevils under control. Applications made just after a rain should be repeated. An excessive number of dust applications favors outbreaks of the cotton aphid, which sometimes becomes of importance in late summer.

A question regarding the relative effectiveness of spraying and dusting frequently arises. The greater efficiency of dusting was shown by experiments in Texas in which the two methods of applying calcium arsenate were compared (3). In an average of three experimental fields the increased yield in the dusted plots was 292.7 pounds of seed cotton, or 83.2 per cent more than the check. In the plots sprayed with calcium arsenate the increased yield was 70.2 pounds or 20.0 per cent more than the check.

Dusting machinery varies from small hand dusters to airplane dusters. The hand dusters are relatively inexpensive when compared with other farm machinery, are indespensible in spot dusting, and on small farms can be used for dusting operations. Machines which apply dust with nozzles to each row are usually the most efficient. The advantages usually claimed for airplane dusting are that it relieves the cotton farmer of the problem of labor management, and that large areas can be dusted quickly.

A failure in preparedness frequently adds to the problem of boll weevil control. This may be expected since the pest is erratic in occurrence. Since the crop acreage involved may be very large, local supplies of calcium arsenate and of machinery are quickly exhausted when an outbreak occurs.

SUMMARY

The insecticidal control of the boll weevil and the codling moth are similar in that the fruiting parts of their host plants must be protected over an extended period. The periods when protection is required are coincident with the periods of abundance of the pest and must necessarily follow seasonal history. The problems differ because of the extreme variability of injury by the boll weevil from year to year and

from field to field. For this reason no inflexible schedule of insecticidal applications is practical and no general recommendation for its control which fits all conditions can be made.

The insecticide should be applied only when and where active injury is evident. Location of infestations is facilitated by a knowledge of seasonal history and habits. Boll weevils attack cotton when it begins fruiting near places where they hibernated. Their short life cycle, which under most favorable conditions may be completed in 16 days, together with their high fecundity makes possible rapid multiplication. As their numbers increase they move to the nearest cotton and ultimately may migrate over large areas. Weevils are abundant enough to cause extensive injury only when the summer is warm and wet. The number which appear in the fields when squares are first formed, depend upon the number which developed during the latter part of the previous season, and upon their successful hibernation.

Control depends either upon dusting the spots where weevils first occur or upon dusting whole fields if infestations are scattered. The cost of calcium arsenate necessary for dusting an acre of cotton three times, at 1941 prices, was about a dollar and a half, which is relatively light compared with that of the other pests discussed in the last two chapters. If spot dusting is employed the average cost for the acres protected is still less.

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CHAPTER XVII

POISONED BAITS

Poisoned bait, scattered broadcast, is often used in control of certain crop pests which are known to be general feeders and which feed or spend at least a part of each day on the ground. The bait should be more attractive to the pest than the other food available at the time. Among the insects for which this method of control is used are grasshoppers, certain Noctuid caterpillars including armyworms and cutworms, and a few broadnosed weevils of the subfamily Otiorhynchinae. Poisoned bait may have an advantage when it is necessary to use an insecticide which is too active to apply on plants with safety. In addition to the use of poisoned baits in control of crop pests they are also used in control of many household insects.

Baits are sometimes used in traps as a supplementary means of insect control, or to indicate the presence or abundance of insects like the codling moth or the Japanese beetle. Baited sprays also may have a limited usefulness.

Since poisoned bait is used most extensively in grasshopper control, the grasshopper problem will be given chief consideration in connection with its use.

THE GRASSHOPPER PROBLEM

Grasshoppers, or locusts, are among the most important insect pests in the United States. They are undoubtedly insects of first importance on the Great Plains and throughout the arid and semi-arid regions of the West. They are also among the most important insect pests of the world and probably have always been so. The "locust problem" appeared, Uvarov (21) suggests, at the earliest dawn of agriculture, and the most ancient monuments of civilization, such as those of Assyria and Egypt, contain beginnings of"locust literature". Probably the most widely known ancient record of occurrence of locust outbreaks is that of the Exodus*.

The methods of grasshopper control have received an unusual amount of careful investigation. When properly applied, they rank among the most distinct entomological successes. Of most importance in control is a knowledge of the likelihood of an outbreak for a long enough time before it occurs to give opportunity for adequate preparation. The hatching period of the destructive species, where their eggs are deposited, their feeding habits, their migratory habits, and the period when they can be most readily destroyed should be known. This is necessary for determining the time and place for applying remedial measures. In some regions this may require a further study of the species involved. A knowledge of the conditions favoring abundance may be an aid in predicting outbreaks and in preventing them. The materials that should be used in control are well known and are the least variable part of the problem.

General recommendations for the control of grasshoppers in the United States are usually the same, regardless of the species involved. The habits of the different species although similar, vary, however, and may make advisable modifications to suit a local problem.

Grasshopper control fails to a greater or less degree because of unpreparedness for an outbreak. Even if available materials for control are on hand, sometimes a part of the public fails to make up its mind to act when the "hoppers" are most easily destroyed.

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*"For they covered the face of the whole earth, so that the land was darkened; and they did eat every herb of the land, and all the fruit of the trees which the hail had left; and there remained not any green thing in the trees, or in the herbs of the field, through all the land of Egypt."--Exodus 10:15

Distribution

As already stated, the grasshopper problem in the United States is most acute in the Great Plains and the arid West. Grasshoppers are the dominant insect pests wherever grass or uncultivated herbaceous cover is the dominant type of vegetation. In the Middle Western, Eastern and Southern States, where much of the area is in cultivated crops or in woodlands, damage by grasshoppers is more often local. Most frequently this is in the vicinity of pastures and meadows or grasses and perennial legumes.

The world distribution of grasshoppers is similar to that in the United States, and is of interest because of its resemblance to our own problem. The distribution of grasshopper plagues in the world as mapped by Uvarov (21) is as follows: In Europe they are most destructive along the Mediterranean, from Spain eastward, around the Black and Caspian Seas, and the Russian steppes. All of this is a region of low rainfall. In Asia there are two large regions which are subjected to severe injury. The larger is a broad strip extending from southern Russia to the Yellow Sea, crossing the plains of Tartary, northern Turkestan, southern Siberia, and Manchuria. The other covers Asia Minor, Arabia, Persia, Afganistan, and the savannah and wheat belt of western India, and one arm extends northward, west of Tibet and China. Doubtless the intensive type of agriculture prevailing in part of this territory has a repressive effect upon the group. In Africa grasshopper injury is most acute in the Mediterranean region in the highlands of Morocco and Tunis, and in South Africa and Madagascar. Periodic plagues also occur in the Nile Valley, Abyssinia, and extend southward to South Africa. There is another area frequently infested, extending from east to west across Africa, between the Sahara and the tropical rain forest. In South America the area of most injury is in southern Brazil, Paraguay, Uruguay, and the Argentine pampas. There is also a grasshopper plague area in northern Australia.

If a comparison is made between this map of grasshopper abundance and a botanical map of the world, it will be observed that as a rule the regions subjected to grasshopper plagues are also regions of grassland. In South Africa, where most frequent and severe injury has been suffered, the region is largely semi-arid grassland, with an annual rainfall of less than 20 inches, which includes a part of Kalahara desert. In climate and vegetation, South Africa may be compared with our own arid and semi-arid West.

Species of Importance in the United States

Of the many species of grasshoppers in the United States, only a few are of economic importance, and these species vary in host preferences and in the amount of injury they cause throughout their range. The lesser migratory grasshopper* is sometimes considered as the most destructive species in the United States. It is distributed all over the whole country and is usually one of the species concerned whenever grasshopper injury occurs. The Rocky Mountain grasshopper** which caused the severe damage during the 70's is believed to be the long-winged phase of this species. The large differential grasshopper*** is probably the most destructive species on corn and succulent crops in the southern part of the Great Plains and in the southern part of the Mississippi Valley. Farther north it is gradually replaced by the similar two-striped grasshopper+. In the northern part of the central states and in the northern Mountain states, the pellucid grasshopper ++ is one of the most important species.

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*Melanoplus mexicanus (Sauss.)

**M. mexicanus spretus (Walsh)

***M. differentialis (Thos.)

+M. Bivitattus (Say)

++Camnula pellucida (Scud.)

Most species of grasshoppers are not destructive to crops. Some species have a very narrow host range and do not feed on plants of economic importance. Some may be considered beneficial because they are limited to certain weed hosts (1).

Periodicity of Outbreaks

Grasshopper outbreaks are periodic. Some injury or local outbreaks may occur every year, but as a rule, the great plagues occur only at intervals. Records, which extend over centuries, on migrations of the migratory locust (Locusta migratoria) in Europe illustrate this periodicity better than the much less extensive records of migrations of grasshoppers in the United States. Koppen (14) records 22 outbreaks of this species in southern Russia between the years 1000 and 1861. The distribution of these outbreaks in history may be as definitely related to certain climatic conditions, as the regions in which outbreaks occur can be related to host combinations.

In the United States migrations of the Rocky Mountain grasshopper were recorded as early as 1821 (13). The most destructive outbreak in the United States occurred during the period from 1873 to 1875. During this period migratory swarms of the Rocky Mountain grasshopper were a scourge of the early settlers on the Great Plains from Canada to Texas. This was during the latter part of an extended succession of summer droughts from 1869 to 1875, inclusive. No extensive migrations of this character have occurred since that time. The most serious losses because of grasshoppers since the migrations of the 70's occurred from 1931 to 1937, with peaks of destructiveness in 1931 and 1936. This has been accompanied by a drought cycle extending more or less continuously from 1929 to 1936, inclusive. Less extensive outbreaks in western Kansas in 1913 (2, 6) and in Montana in 1926 also followed a series of dry summers in those states.

Character of Outbreaks and Destructiveness

Grasshopper outbreaks fall into two quite different categories. The injury of one type is caused by the so-called resident grasshoppers. These species may be migratory to a degree and may move from farm to farm, or from longer distances. This is the type of outbreak that is most usual and will receive most attention in this discussion. The other type is caused by more distinct migrations during which grasshoppers fly long distances from their breeding grounds. This is much more spectacular and has received more attention from history.

The records of injury during the great outbreak of the Rocky Mountain grasshopper in 1874 illustrate the degree of devastation possible from a great migration (14, 15). The early settlers have reported swarms of migrating grasshoppers alighting on their crops as thick as falling snow, and that everything green was stripped 24 hours after the invasion. In 1875 a swarm required six hours to pass over Bismark, North Dakota. In the Third Annual Report of the Kansas State Board of Agriculture, for 1874, replies are given to inquiries from 30 counties scattered over the state in which were reported the total or almost total destruction of all crops green at that time. The United States Entomological Commission estimated the corn crop was reduced about 53 per cent in the states of Nebraska, Kansas, Iowa, and Missouri.

The destructiveness of grasshoppers which are considered resident species on an area in southern South Dakota and northeastern Nebraska during 1931 is described by Parker and Shotwell (12). On a total of 17,000 square miles, 75 per cent of all crops were destroyed. Outside this area of greatest destructiveness was a region comprising about 13,000 square miles, in which at least 25 per cent of all crops was destroyed. This destruction was due largely to the differential grasshopper and the two-striped grasshopper, the former being slightly the more important.

These outbreaks resulted in extreme injury and are periodic. It should not be inferred, however, that regular annual injury does not occur. While major outbreaks may be separated by long periods of years, the tax levied by grasshoppers in situations favorable to them is as regular as that of most other pests attacking major crops in the United States, although it fluctuates annually.

Seasonal History

Most of the species of grasshoppers in the United States have a single generation a year. The lesser migratory grasshopper may have two generations in the southern part of its range. Almost all of the species of economic importance pass winter in the egg stage in the soil. The eggs hatch in spring or early summer and the nymphs mature from midsummer to fall. There are five or six nymphal instars. If there is a food shortage, hoppers tend to migrate from their breeding grounds. This may begin with the third nymphal instar. Nymphs may migrate more than five miles and adults several hundred. Following a period of feeding is the reproductive period when the adults deposit eggs in the soil in packets or pods. The period of hatching, of maturity, and of egg deposition, of course, varies with the species, and with the season. The hatching period of a single species, the two-striped grasshopper, may extend over six weeks (19). If during some seasons the majority of eggs hatch unusually early, the early nymphs may be subjected to unfavorable conditions with the result that most of the survivors are those which hatched nearer the average time. While most grasshoppers are single brooded, there is a succession of species throughout the season which sometimes, to the layman, give the appearance of a succession of generations. An extended hatching period may also give this impression. There are a few species which winter as adults and as nymphs.

Habits

Grasshoppers are diurnal. Feeding activity of the destructive species usually begins in the morning when the temperature rises to about 68° or 70° F. and when the sun is shining. During hot summer weather this may be soon after daybreak. After three or four hours feeding activity declines. Shotwell (17) found that the lesser migratory grasshopper may have a secondary feeding period late in the afternoon after the temperature begins to fall. Sunlight favors feeding. During periods of cool, cloudy, or rainy weather, grasshoppers can subsist for days without taking food.

The places and manner of oviposition varies with the species and sometimes is of importance in control. The differential, the two-striped, and the pellucid grasshoppers tend to concentrate their egg masses in the roots of grass clumps in headlands around margins of fields. For this reason they may survive in regions where most of the land is under cultivation. On the other hand, the lesser migratory and red-legged grasshoppers deposit eggs in bare spots over fields of small grain or grass land. Most species deposit eggs in the soil at a depth of one to two inches. Certain range species deposit egg pods horizontally just under the surface.

Certain locations or areas are particularly attractive to grasshoppers as places for oviposition. In Montana, Mills (9) refers to the eggs of the migratory grasshopper being concentrated in an "egg bed" involving parts of 13 counties, and stated that grasshoppers migrated for several hundred miles into this region. In Arkansas the differential grasshopper has been observed to concentrate in certain ravines for oviposition. Such concentration of centers of oviposition also concentrates the problem of control.

Life History

Since climate is a controlling factor in determining grasshopper abundance, the more important life history studies have given attention to the effect, particularly of temperature upon the various species concerned.

The rate of development and activity of grasshoppers, as of other insects, is accelerated by increasing temperatures. Physiological zero for the migratory grasshopper, according to Parker (11) is 62.6° F. The average time required for development of the nymphal stage of this species at 71.6° F. was 79 days; at 80.6° F. was 42 days; at 89.6° F. was 27 days; and at 98.6° F. was 21 days. This shows a consistent acceleration in rate of development as the temperature increased. Other species studied also show a similar acceleration of development by increasing temperature. The more southern species which have been studied require more time for development at the same temperature than northern species. For instance the differential grasshopper requires four to nine days more for nymphal development than its more northern counterpart the two-striped grasshopper (19).

Temperature also affects growth in other ways. Parker found that the lesser migratory grasshopper, when reared at constant temperatures of 71.6° F. and 80.6° F., had six nymphal molts. At temperatures of 89.6° F. and 98.6° F. they had five nymphal molts. Those reared at high temperatures are lighter in color than those reared at low temperatures.

The effect of temperature on feeding and activity is still more significant. Parker (11), studying the lesser migratory grasshopper, and Langford (8), studying the two-striped grasshopper, state that the temperature range for feeding is from 68° F. to 100.4° F. with the optimum about 98.6° F. Parker (11) found that a grasshopper would eat 25 times as much at 98.6° F. as at 80.6° F.

The capacity for reproduction is also increased with increasing temperature, up to 89.6° F. As temperature goes higher, the amount of egg deposition declines. Parker found that females of the lesser migratory grasshopper would deposit an average of 8.0 pods each at 89.6° F. The maximum record for a single female was 15 egg pods. The pellucid grasshopper responded in a similar manner to temperature. The average number of eggs in a single packet or egg pod of the lesser migratory grasshopper, according to Shotwell, is about 20.

As might be expected, grasshoppers eat more as they increase in size, the capacity more than doubling with each molt. Langford (8) has found than an adult female of the two-striped grasshopper will consume about 100 times as much as a nymph of the first instar of the same species. The size of the species is also a factor in the amount of food consumed. Adults of the large species, like the differential grasshopper, eat three times as much of those of the smaller species like the red-legged grasshopper.

Conditions Favoring Outbreaks and Migration

Conditions favoring grasshopper outbreaks are usually described as a succession of warm, dry summers. This might be assumed from the biological data just cited. The assumption can be confirmed by reviewing the weather records of years when outbreaks have occurred. High temperatures favor rapid growth, and what is more important, increase the capacity for food consumption and reproduction. Heavy rainfall at the time the nymphs are hatching and during the oviposition period are probably the most important checks upon the abundance of grasshoppers. Cool rainy weather during the early nymphal stages was a very important check on the differential grasshopper in Arkansas during the spring of 1938. Excessive humidity increases the activity of

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entomophagous fungi which may also reduce the numbers of grasshoppers. The history of outbreaks in America has shown that all the more important outbreaks have followed a succession of dry summers and that all of them ended with a wet season. Nevertheless, drought can be so excessive that there is not food enough to develop eggs. Reproduction of the differential grasshopper was almost completely checked in northwestern Arkansas by the excessive heat and drought in 1936.

Of equal importance to favorable weather for increasing the abundance of grasshoppers are suitable hosts or host combinations. The grasshopper injury in the United States and elsewhere in the world is most severe in grass grown plains. While grasshoppers may be regarded as general feeders most species have distinct host preferences, and an abundance of its preferred hosts may determine the abundance of a given species. For instance the differential grasshopper has become abundant as a result of the agricultural development of the Great Plains. It was not a common species in the prairies and formerly occurred only in rank vegetation particularly along water courses. With the replacement of the wild grasses by corn and other succulent crops it has become a dominant species. Within the last decade it has become an important pest in the Delta of northeastern Arkansas because of the replacement of large acreages of cotton by soy beans. Adults of this species fed on soy beans by Sanderson (16) deposited an average of 304.6 eggs while those fed on cotton deposited only 73.0 eggs. Moreover the rate of growth was also more rapid and the mortality much less for nymphs fed on soy beans than for those fed on cotton.

The soil type, covered with suitable vegetation, probably also affects the abundance of certain species. The lesser migratory grasshopper prefers to oviposit in grass grown on sandy soil, and does not breed abundantly in heavy soils nor where the favored locations are cultivated. The soil type relationship of most species have not been fully studied.

Grasshoppers have many natural enemies which are sometimes credited with checking outbreaks. The eggs are attacked by the larvae of blister beetles, ground beetles, and bee flies (Bombyliidae). Sarcophagid and Tachinid flies are parasitic on the nymphs and adults. Grasshoppers are also seen carrying red Trombidiid mites, and are sometimes heavily infested with nematodes. During wet seasons they are also attacked by entomophagous fungi and bacteria. At any time they are preyed upon by many species of birds and some mammals.

Migrations

Most species of grasshoppers are to a degree migratory, and some of our resident species develop larger wings at some times than at others. Grasshopper populations within a field and from field to field are constantly shifting according to Shotwell (17). The migrations over five miles by nymphs of the lesser migratory grasshopper have been noted by this investigator and the adults of a number of species move much greater distances. High temperatures and dry weather, either directly or indirectly through their effect on food, may cause grasshopper migrations. Parker (11) found that nymphs of the lesser migratory grasshopper, when reared on food with low moisture content, tend to produce adults with longer wings than those reared on more succulent food. He presented evidence that the Rocky Mountain grasshopper is simply a long-winged form of this species. Later Faure (4) reported that he reared the long-winged form from eggs of lesser migratory species. Migrations of the Rocky Mountain grasshopper have not occurred since the outbreaks of the 70's and it has been inferred that this is because conditions favorable for its development have been removed by cultivation of so much of its breeding grounds. Parker and Shotwell (12) in their observations on the differential grasshopper noted longer flights and a greater migratory tendency in 1931 than are ordinarily considered possible for this clumsy species.

While many species are to a degree migratory, there are a few species of grasshoppers in the world which occasionally develop long-winged migratory forms that intermittently sweep over a wide expanse of territory, causing locust plagues. The relationship between the resident non-migratory form and the long-winged migrants of some of these has been accepted for years. The long-winged forms apparently develop only in certain restricted areas. The presumed relationship between the lesser migratory and the Rocky Mountain grasshopper has been mentioned. The outbreaks of this species originated in the dry lands east of the Rocky Mountains in Wyoming and Montana. The migratory locust of Europe and Asia, *Locusta migratoria*, has long been regarded as a morphological phase of *L. danica*. The desert locust, *Schistocerca gregaria*, is a migratory phase of *S. perigrina*, and was undoubtedly the locust of the Exodus. The brown locust of South Africa, *Locusta pardalina*, is subject to frequent periodic development of a migratory phase, the outbreaks arising in semi-arid plains, including the Kalahari desert. Eight species which occasionally develop long-winged migratory phases are discussed by Uvarov. Quite likely some of the less well known species also have migratory phases. The long-winged grasshopper* of our arid Southwest is at times migratory and flies in swarms seen for long distances.

The most elaborate study of causes of development of a migratory phase have been made by Faure (3) of the South African brown locust. In his experiments he eliminated most of the physical factors and concluded that crowding produced the migratory phase.

Control

For the control of grasshoppers chief dependence is placed on the scattering of poisoned bait, which has been used in the United States since 1913 (2, 6). The materials used in grasshopper bait are a carrier, the poison, and water. Sometimes attrahents are added. The moisture itself in the bait is undoubtedly an attractive component (19). The so-called "Government Formula", which is now generally recommended (13) is as follows:

Millrun bran, mixed feed, or shorts	25 pounds
Sawdust (3 times bulk of bran)	3½ bushels
Liquid sodium arsenite	½ gallon
Water	10-15 gallons

or

Bran	50 pounds
Sawdust (equal in bulk to bran)	2½ bushels
Liquid sodium arsenite	½ gallon
Water	10-12 gallons

These materials are varied somewhat, depending upon their availability. Where wheat bran is readily available and sawdust is not easily secured, it is used exclusively in the carrier. White arsenic or Paris green are frequently substituted for sodium arsenite, using four pounds to 100 pounds of the carrier. Paris green is relatively expensive and is not recommended except where only small amounts of bait are needed. The amounts of water used depends somewhat upon the absorbing quality of the carrier. The particles of bait should stick together, but the mixture should not be sloppy. As an attractive element, two gallons of cane molasses is sometimes added to 100 pounds of bait and under some conditions this appears to add to its effectiveness. For many years various other attrahents were recommended, the one most frequently included being amyl acetate. Citrus fruits or vinegar occured in earlier recommendations. The inclusion of these materials is no longer considered justified by cost. As for instance, experiments in Oklahoma in 1936 (23) showed that a bran

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Dissosteira longipennis

bait without attrahents was 98.5 per cent as efficient as the standard bait which included them. A bait in which the carrier was 50 per cent sawdust and 50 per cent bran and without attrahents was 95.7 per cent as efficient as the standard bait. Sawdust from all species of trees are not equally satisfactory. When grasshopper bait is prepared, the dry part of the bait should be thoroughly mixed before the liquid is added.

Poisoned bait is most frequently scattered broadcast by hand from the ends of wagons or trucks. Various sorts of distributors are also used. Aeroplanes have been used both in the United States and South Africa. Bait should be distributed so that the particles are about the size of grain and never in lumps. The amount of poison used depends upon the character of the infestation. Where grasshoppers go to cover along the margins of fields at night, bait scattered around the margins is most effective. Sometimes three or four applications made at intervals of a few days may be necessary to bring an outbreak under control. Where extensive migrations occur a larger number may be necessary. It is usually estimated that ten pounds of bait is required for a single application on an acre.

The control of grasshoppers by poisoned bait is sometimes strikingly effective. Poisoned grasshoppers sometimes accumulate in piles among weeds along the margin of fields, where they have gathered to die. Where this has occurred, a single application of bait has sometimes destroyed the infestation. However, the results are not uniformly satisfactory. To secure the best results it is necessary to scatter poison just before the time of the day when hoppers begin feeding. During the heat of summer grasshoppers begin to feed as soon as the sun comes up. When this is the case, bait distributed before daylight is most attractive to grasshoppers, while that scattered the evening before has lost its freshness. During the cooler parts of the year grasshoppers do not begin feeding until later in the morning when the temperature reaches 70° F., and the optimum time for distribution of the bait is proportionately later. Bait is consumed more readily by grasshoppers when a warm sunny day occurs following a few days of cloudy or cool weather, during which time the grasshopper has been fasting.

Grasshoppers will consume large quantities of poison during the last two nymphal instars and during the first two weeks of the adult period. For this reason they are more easily poisoned at this time in their life cycle than later. Poison applications are frequently disappointing in the percentages of hoppers killed when made after grasshoppers are sexually mature and when they spend much of their time mating and depositing eggs. During the reproductive period, crop destruction is less, but killing grasshoppers is still important for otherwise eggs which give rise to the next generation will be deposited.

Bait is more readily eaten by grasshoppers during dry weather than during wet periods. During periods of drought hoppers have been greatly attracted to moist bait, without attractive elements and even when the carrier was all sawdust. During periods when humidity is high the bait appears to be less attractive and at this time the addition of molasses is most useful.

An objection to the use of poisoned bait is occasionally raised that it may kill game birds or may poison livestock. Extensive experiments in Oklahoma (22) with poultry and game birds have shown there is little likelihood of poisoning game birds if the bait is distributed in a reasonable manner. In these experiments poultry and birds were confined in pens on which bait had been distributed at the rate of 100 pounds to the acre, or ten times as much as is normally recommended and no symptoms of poisoning occurred. There has been found to be little danger of poisoning livestock by pasturing them on fields on which bait has been distributed, provided it was scattered in small particles and not in lumps. Recent surveys in Iowa have shown

that following a year of grasshopper abundance the quail were more numerous where grasshoppers were controlled by poisoned bait, doubtless because grasshopper control protected the food plants of the quail.

It should be recognized, of course, that sodium arsenite, or other arsenicals substituted for it are vary active poisons and should not be handled carelessly. In handling poisoned bait it is usually recommended that the hands be greased, with particular care being given to working the grease around the finger nails, or that rubber gloves be used.

Other methods of control are frequently recommended. Outbreaks can be prevented or reduced by destruction or deep burying of the egg pods in winter by plowing situations in which they oviposit (9, 13). Cultivation of land in the breeding grounds of the Rocky Mountain grasshopper has been credited with the failure of the species to reappear in over half a century. Although only partially effective, winter disking of alfalfa fields has been recommended and cleaning up of headlands has a repressive effect upon a number of species.

An insect catcher, the "hopper dozer", was formerly considered as useful against nymphs and heavy-bodied species like the differential grasshopper. The "hopper dozer" is a long pan on runners, back of which is a high metal shield. When in use, the pan is filled with kerosene, and is dragged over fields. Hoppers jumping up strike against the shield back of the pan and fall into the kerosene. Obviously it can be used only on crops like alfalfa, and its general usefulness is local. Grasshopper traps built on a similar plan have also been used. When these insect catchers are now recommended they are considered as only supplementary means of control.

Public Interest

On account of the widespread devastation which grasshoppers may bring and on account of their migratory habits, this problem of control has never been considered as one to be met strictly by the private individual but rather has been one of public responsibility. There were very few professional entomologists in the United States before the outbreaks of the Rocky Mountain grasshopper in the seventies. Following this, a number of positions for entomologists in the states were created and the work of Federal entomologists was really begun. For many years, states and counties furnished funds for purchase of poison by farmers when outbreaks occurred. Since the outbreaks of the present decade, there have been federal appropriations for the control of grasshoppers, as for instance in 1936, the appropriation was $1,400,000. Poison and sometimes poisoned bait have been furnished to the farmers without cost. As a rule, the distribution of poison was administered and directions for control were given by the Extension Service in the states concerned.

Since the grasshopper problem has been recognized as one of public concern, annual surveys of grasshopper population have been made in the midwestern states where the problem occurs most regularly. These surveys begun following the outbreak of 1931, amply justified by the dependability of the recommendations based on them. The surveys have been made under the leadership of entomologists of the United States Department of Agriculture with cooperation of entomologists in the states concerned (18, 20). They are designed to locate and evaluate potential infestations for the purpose of determining in advance where injury is likely to occur, the probable severity of the outbreak, and the amounts of poison needed. A survey of the number of adults in a given area made in late summer and of the number of eggs, serves as a basis for estimating the possible severity of the outbreak the following season. This may be checked by a nymphal survey the following spring to improve the accuracy of the prediction. The utility and accuracy of forecasts of grasshopper abundance is probably favored by the relatively long life cycle.

SUMMARY

Grasshoppers are potentially able to destroy all vegetation within a region more completely than any other insect pests. They occur at times in destructive numbers in all grass grown plains of the world. The occurrence of outbreaks is generally associated with periods of drought.

Control by the use of poisoned baits depends upon the habit of feeding upon the ground during a part of the day. Most of the destructive species in the United States have only one generation a year and for that reason the period of destructiveness, and the period when control should be undertaken can be accurately anticipated. Bait is consumed most voraciously by nymphs and by those adults whose reproductive period has not begun. It is also most effective if applied in the morning before the daily feeding period begins.

On account of the migratory tendencies of destructive grasshoppers their control is a matter of concern to the public as well as to the individual. Surveys may be made near the end of one growing season to determine the expected abundance the following year. This information is useful in locating adequate supplies of poison in regions where outbreaks are expected.

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CHAPTER XVIII

CONTROL OF INSECTS BY GOVERNMENTAL REGULATION

More than half the insect damage in the United States is caused by species of foreign origin which have been introduced accidentally. For example, the Hessian fly, the European corn borer, the rice weevil, the codling moth, the San Jose scale, the gypsy moth, the black scale of citrus, and the cotton boll weevil are not native to the United States. Many of these insects are among the most important, if not the most important, pests of the crops attacked. It is difficult to estimate the losses which they cause directly to the crops concerned or the money spent combatting them. There are also many other foreign insects which if introduced might be as destructive as those which have already become established here. The danger of introducing them increases with the growth of foreign commerce.

To prevent the introduction of foreign insects and to prevent the spread of pests already in the United States, systems of inspection service and of quarantines have been developed under the control of the Federal Government and of the various states. In addition to enforcing quarantines, some of these regulatory organizations have the task of eradicating insects which recently have become established in restricted areas. Control of insects by governmental regulation involves then, both exclusion and eradication, or methods of control which require powers beyond those of the individual.

Regulatory control is of comparatively recent origin. The federal government entered the regulatory field in 1913. In some of the states the work is much older. Many of the possibilities of regulatory work are still untried. It is likely that we shall be much more dependent upon governmental regulation for the control of insect pests in the future than we are now. There is always the danger that quarantines and official suppression of pests may at times be an unnecessary burden, and may add to the costs, both of the producer and of the consumer. Most regulatory organizations which are concerned with insect pests are also concerned with plant diseases. Many of the general principles apply to both groups of pests, but we shall deal only with insects.

The administration of domestic and foreign quarantines on account of insect pests and plant diseases is under the control of certain divisions in the Bureau of Entomology and Plant Quarantine of the United States Department of Agriculture. This work was at first under the charge of the Federal Horticultural Board which was later reorganized as the Plant Quarantine and Control Administration. This administration was subsequently merged with the Bureau of Entomology. This control is based on the federal plant quarantine act of 1912 and subsequent amendments. This act gives the Secretary of Agriculture power to promulgate quarantines to include any state, territory, or district of the United States or any portion thereof, when the Chief of the Bureau shall determine that such quarantine is necessary to prevent the spread of a dangerous plant disease or insect infestation. A quarantine may be established without its being necessary to determine the actual limits of infestation and emergency quarantines may be quickly put into effect without long preliminary investigations. The powers of the Bureau of Entomology and Plant Quarantine are broadened further to include in addition to plants and plant products "any class of stone or quarry products or any other article of any character whatsoever capable of carrying any dangerous plant disease or insect infestation". This Bureau maintains a large staff of inspectors to enforce its rulings. Port inspection is facilitated through cooperation with the customs office. Domestic quarantines are often carried out by collaborators who are actually cooperating state employees.

State Regulatory Organizations

In all states there is now some official organization whose duties, in part at least, involve regulatory work relating to insect pests. These organizations vary from one state to another, but may be brought together into three general types. In a number of states a special organization has been established for regulatory work. The State Plant Board in Arkansas is an organization of that type. Regulatory work is sometimes handled in a branch of the state department of agriculture, as in California and Pennsylvania. It may also be under the direct charge of the entomologist of the State Experiment Station, who is designated by law as being also State Entomologist. Obviously, there cannot be a strict classification, as there are combinations of the various types.

In Arkansas the State Plant Board is the official body in charge of this work. Under provisions of the Arkansas Plant Act of 1917 and subsequent amendments, the Plant Board is "vested with authority to promulgate rules, regulations and quarantines to prevent the introduction and dissemination and to provide for control and eradication of dangerous insect pests and plant diseases". Its authority also includes prevention of nursery frauds and promulgation of grades and standards for agricultural products. Persons engaged in commercial pest eradication after having passed an examination may be licensed by the Board.

The Board is composed of seven members as follows: The Entomologist of the State Agricultural Experiment Station; the Plant Pathologist of the State Agricultural Experiment Station; a practical cotton grower, actively engaged in the business, to be appointed by the Governor for a term of two years; a practical horticulturist actively engaged in the business, to be elected by the State Horticultural Society for a period of two years; a nurseryman, elected by the state nurserymen's association; a representative of the State Seed Growers Association; a representative of the State Plant Growers Association. This Board shall employ and prescribe the duties of a Chief Inspector, who may employ such deputies or other employees as may be required.

The active administration of the rulings of the Plant Board is in charge of the Chief Inspector. In fact, most of the rulings originate with him. The Board members serve without compensation and have other interests, and cannot give more than passing attention to regulatory work. The Chief Inspector's force now includes, besides himself, deputy inspectors and a clerical force.

In Arkansas the Plant Board has confined its activities, so far as insects are concerned, to preventing the introduction and dissemination of pests, on nursery stock, sweet potatoes, and cotton seed.

California will serve as an example of the second type of organization. This state has one of the largest and most elaborate organizations of regulatory work of any state in the Union. It maintains a large Bureau of Quarantine and Pest Control in the division of Plant Industry of its Department of Agriculture. In addition, each county has an agricultural commissioner with a force of inspectors and deputies who are really pest control officers. The insecticide laws are also administered by the Department of Agriculture through its Division of Chemistry and through the County Agricultural Commissioners.

The entire organization is in a general way under the control of the State Department of Agriculture. In the Department itself division chiefs and their deputies must pass the state civil service examinations before appointment and their term of office is indefinite.

The County Agricultural Commissioners are appointed for a period of years by the County Board of Supervisors, from a list of eligibles provided by the Commissioner of Agriculture. The County Commissioner is responsible to the State Department of Agriculture to an extent, he must make reports to the State Department, and may be removed from office before his term has expired, for misconduct or incompetence, by a trial board of three, of which the State Director is Chairman. The County Commissioner appoints his own deputies and inspectors, who are removable at will. The salaries of all of these regulatory officers is fixed by state law. The number of people engaged in regulatory work in the state of California in 1933 was approximately 140 employed directly by the state and 350 by the counties.

The County Agricultural Commissioner and his inspectors are largely responsible for pest control in their territory. This is probably their greatest burden. Each inspector is assigned a certain territory. In a sense he is held responsible for insect outbreaks in this territory. He is expected to advise growers regarding control of pests. In many instances accurate timing of control measures requires careful observation and a thorough knowledge of the pests in question. If the grower neglects to follow the advice, the inspector may serve a notice declaring the pests found on the property to be a public nuisance and directing the owner to control the same within a stated time. If the work is not done at the expiration of the days of grace, the law states that "it shall be the duty of said (county) commissioner to cause said nuisance to be at once abated by eradicating or by controlling said plant diseases, insect or other animal pests or said noxious weeds". The cost shall be at county expense and shall be charged against the property as a first lien, taking precedence over all other encumbrances except taxes. It is held that the multiplication of pests on any man's property is not his own business but a matter of public concern.

The County Agricultural Commissioner is also designated as "quarantine guardian" and it is his duty and that of his deputies to enforce quarantines and carry out inspection of nursery stock or other plant products which may be carriers of noxious insects or plant diseases.

The sale of insecticides and of specialized work in insect control is regulated by the State Department of Agriculture and the County Agricultural Commissioners. The sale of adulterated or misrepresented poisons is prohibited by law. All manufacturers, importers, dealers and salesmen must be licensed annually by the State Department of Agriculture. Any person, firm, etc., engaging in the business of eradicating or controlling insects (such as fumigation firms) are required to secure certificates from the County Agricultural Commission before they are allowed to operate in any county.

The rearing and distribution of insect enemies of insects, like lady beetles, and parasitic hymenoptera, has also been a part of the regulatory organization in California.

In some states like Connecticut, the office of the Entomologist of the experiment station and of the State Entomologist is combined. This is the third type of organization. The staff of the State Entomologist's office may be largely separate from the staff of the Department of Entomology in the Experiment Station. The line between their duties is not always clear, however, for at least some of the inspectors engage in experimental work.

Systems of Quarantine

The system of handling quarantines have been described by Smith et al (2) as follows: "There are four principal systems of plant quarantine: Inspection at point of destination; inspection and certification at point of origin; complete embargoes; and controlled introduction. That in general a quarantine cannot be made effective

[illegible]

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when reliance is placed solely on inspection of shipments of plants and plant products either at origin or destination to determine the presence of infestation or infection. A plant quarantine, to be effective, must either: (1) exclude host plants or parts thereof which may carry the pest or disease, originating in the infested or infected area; (2) permit the entry of hosts from the infested or infected area only if they have been produced and packed under such conditions as to preclude their carrying the pest or disease; (3) permit the entry of hosts from the infested or infected area only if they have been subjected to treatment which will free them from live infestation or infection.

"A plant quarantine, in order to be effective and justifiable, must provide for the closing of the major avenues of entrance of the pest or disease, and must be maintained by a force sufficient actually to carry out its provisions.

"The possibility of eradicating a pest or disease greatly increases the importance of the quarantine policy. The failure of a quarantine to prevent the incipient establishment of a pest or disease does not exclude the possibility of preventing _permanent establishment_, since it may be followed by a successful eradication campaign. Eradication campaigns should be undertaken only after a most thorough analysis of the situation from economic, biological, sociological, and legal standpoints. When these are all favorable, quarantine officials should not hesitate to urge this action. It is not necessary to accomplish by artificial means the destruction of the last individual of the pest or pathogenic organism in order to bring about eradication. In some cases at least, the destruction of the major portion of such organisms will result in the completion of the job by Nature herself."

Costs of Regulatory Work

The purpose of regulatory work, as already stated, is to prevent the introduction of new pests into a territory, to prevent the spread of pests already established, and occasionally to eradicate or suppress pests now present. Of necessity regulation results in hardship to some through interference with trade or destruction of property. This affects the producers at once and the consumers at least indirectly through increased costs of the products concerned. The cost in taxes should be added to the direct costs. To be justified it must be assumed that the temporary disadvantages of regulation will be offset by a greater long time advantage later. Quarantines unwisely set up may result in restrictions of trade without compensating effects. It is sometimes charged that state quarantines have the effect of interstate tariffs.

The value of regulatory work and the conditions under which it should be resorted to may be determined by study of how it has affected the distribution and establishment of pests foreign to the United States.

THE MEDITERRANEAN FRUIT FLY

The Mediterranean fruit fly* is the most destructive species in the family Trypetidae, and is probably the most important insect enemy of tropical and subtropical fruits. While it is best known as a pest of citrus fruit, it may be fully as injurious to peaches and other deciduous fruits where they occur within its range. Its importance is based on the wide range of hosts it may attack, on its extended distribution around the world, and on the continuous threat to the fruit industry in countries where it does not occur. Its exclusion was the object of one of the first quarantines promulgated by the Federal Government. Its sudden and alarming appearance in 1929 over a large part of the citrus belt of Florida, and its practical

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*_Ceratitis capitata_ (Wied.)

extermination the same year following a prompt and aggressive eradication campaign, makes it a suitable example for study of the application of governmental control.

The Mediterranean fruit fly occurs in the tropics and subtropics in parts of every continent. In North America it is now known to occur only in the Bermuda Islands. In South America it occurs in Brazil and Argentina. In the Old World it is distributed in all the countries bordering the Mediterranean, occurring as far north as Paris, France, in Europe and as far south as Cape Colony in Africa. In Asia it occurs only in Turkey, Syria, and Palestine. It is also found in Australia. Its original home is supposed to be equatorial Africa. Of the island possessions of the United States it is found only in Hawaii. It is on the Hawaiian Islands that the most thorough study of this insect was carried on and upon this study the account of bionomics which will follow is largely based (6, 7).

The fruit fly causes injury only in its larval stage. The female fly deposits its eggs in groups just below the skin of the fruit attacked. Upon hatching, the larvae scatter through the fruit. When full grown the larvae drop to the soil where they bury themselves and pupate.

A total of 118 hosts were found to be subject to attack by the Mediterranean fruit fly under laboratory conditions in Florida. This includes all the fruits grown commercially in the United States and in addition the fruiting parts of a number of vegetables including beans, tomatoes, and okra. In Hawaii it attacks all fruit of commercial importance except the pineapple and under some conditions the Chinese banana. Many of the fruits from which it has been reared in the laboratory are seldom attacked in the field. Most fruits are attacked only when they are nearly ripe.

The potential destructiveness of the fruit fly under optimum conditions is shown by its record in Hawaii, where together with the melon fly* it practically ruined the horticultural industry. It was first found in Hawaii in 1910. Within four years it was distributed in all parts of the islands.

Life History and Seasonal History

Under optimum conditions the Mediterranean fruit fly will pass through its immature stages in 17 days. A total of the minimum records for each stage is actually less than this. These individual stage records are: Egg, 2 days; larva, 5 days; and pupa, 6 days. A female fly will begin to deposit eggs within four to six days, making 21 days a possible minimum period for the complete life cycle. A temperature of about 79° F. is considered optimum. In the cooler part of the year in Hawaii, when the temperature is about 68°, 40 to 69 days are required to complete the immature stages. Under unfavorable conditions fruit flies may require three or four months to complete development.

In addition to temperature, food is a factor in the rate of development of larvae. Development is slower in unripe fruits than ripe ones, and also is slower in unfavorable hosts than in favorable hosts.

Adult flies usually live from 30 to 40 days under favorable conditions. With cool weather, adult life is prolonged. At a relatively low temperature, 58° to 62° F., Back and Pemberton (5) found that the majority die within six months and one individual was kept alive for 315 days. Under unfavorable conditions of food or temperature, females may suspend oviposition for a time and recommence again when conditions are more favorable. This ability to wait for favorable conditions is a factor of great importance in the success of the species.

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*Bactrocera cucurbitae Coq.

The largest number of eggs on record deposited by a single fly is 622.

Because of the rapid development of the immature stages under favorable conditions, the generations follow rapidly one after the other, and overlap to such an extent that they cannot be separated. For this reason, the time of occurrence of a given generation has no bearing on time of control measures. A knowledge of the possible number of generations is of importance chiefly because of its relation to the multiplication of the species within a single season.

In those regions where the fruit fly is most destructive, conditions prevail which make possible reproduction of the fruit fly throughout the year. The conditions include a climate with no winter or at best a very mild winter. In addition there must be a sequence of hosts with a degree of maturity suitable for rapid larval development throughout the year. A favorable climate and a sufficiently diversified fruit production occur both in Florida and California, indicating that the fruit industry in either state might be ruined if the fruit fly were ever established there. The injury in Florida in 1929 according to Quayle (8) was the most severe he had ever observed anywhere in the world.

In temperate regions where the fruit fly is able to survive, it may cause injury, although the losses do not compare with those in the tropics and sub-tropics. As for instance, in South Africa the fruit fly is generally distributed. It can be controlled, however, by spraying. Even as far north as Paris it may cause serious damage to late peaches and winter pears. Its world distribution indicates that the fruit fly could be a pest in most of the deciduous fruit regions of the United States and while it might be brought under control, doing so would at least involve extra expense.

Control of the Mediterranean fruit fly by spraying may be practical under some conditions. Since the eggs are deposited beneath the surface of the fruit and the larvae spend their entire feeding period within the fruit, it is obvious that they are not susceptible to direct control by spraying. The adult has a minimum preoviposition period of four days, however, and this period may be prolonged under unfavorable conditions. At this time the adult may be poisoned by arsenate of lead in a solution of sugar and water. This was first tried by Mally in South Africa, and effective protection of peaches was secured. It was also used by Berlese against the olive fly in Italy and later by Illingsworth against the apple maggot in New York. Apparently a baited spray of this type is effective against many Trypetids. In all countries where it was effective, however, the climate was temperate. Experiments in Hawaii showed that the use of baited sprays destroyed many flies and reduced the fly population, but nevertheless conditions affecting their development were so favorable that enough flies escaped to infest all fruit in the sprayed area. The formula used in the latter part of the eradication campaign in Florida was arsenate of lead two pounds, crude brown sugar 25 pounds, molasses 5 gallons, water 100 gallons.

Quarantines

Immediately following the passage of the Plant Quarantine act in 1912 a quarantine was promulgated to prevent the importation of the Mediterranean fruit fly and the melon fly from Hawaii into continental United States. This quarantine has been revised and is designated as domestic quarantine number 13. It now prohibits the importation from Hawaii of all fruits and vegetables in the natural or raw state, on account of the fruit flies. A similar foreign quarantine, number 56, has been promulgated which forbids the importation of fruits and vegetables from certain foreign territories.

Eradication in Florida

In spite of quarantines, an infestation of the Mediterranean fruit fly was found near Orlando, Florida, on April 6, 1929. It soon appeared that the infestation was distributed over 13 counties involving the greater part of the citrus producing area of Florida. Emergency funds were promptly drawn upon, and on May 2, the Federal congress appropriated $4,250,000 for an eradication campaign. To insure unified action, the Florida State Plant Board Commissioner was placed immediately in charge of the work by the Federal government as well as that of the state.

The eradication measures were first directed at the short life cycle of the pest. Under favorable conditions, such as occur in Florida, it not only reproduces rapidly but the entire life of the fly is relatively short. A host-free period was maintained from May 1 to October 1. Growing or planting of vegetables on which the fly might reproduce was prohibited and all fruits were destroyed except citrus fruits which were so immature that they were not susceptible to infestation.

The supporting measure for control was spraying, not only cultivated but wild plants, at regular intervals to destroy any adults that might otherwise survive. As high as 110,000 acres were sprayed in a single week.

While the eradication campaign was in progress, scouting was cntinued to locate new infestations, and to check the results of the eradication programs. The effect of the campaign soon became evident. After August 1929 only three small infestations were found. The last was located on July 25, 1930 and consisted of two pupae found in a sour orange. The quarantine restricting the movement of Florida fruit and vegetables was revoked in November of that year. The entire expenditures for the campaign, state and federal, totaled $7,240,112.90. This has been described as "the most remarkable achievement of the eradication of an insect" (8).

THE GYPSY MOTH

The gypsy moth* is probably the most important defoliator of forest trees in that part of the United States where it now occurs. It was introduced into Massachusetts in 1869, but its distribution in America is still limited to the New England States and adjacent parts of New York and Canada, with some scattered infestations in New Jersey and Pennsylvania, because of the repressive measures which have been in force to prevent its spread. It is one of the most destructive forest insects of Europe and northern Asia.

The advent of the gypsy moth in North America was not sudden and spectacular like that of the Mediterranean fruit fly. Eggs were introduced near Medford, Massachusetts, by a French mathematician with the fantastic notion that the species might be used in breeding a more hardy race of silk worms. Some larvae escaped, and an apparently unsuccessful attempt was made to destroy them. Little further attention was given to the species for 20 years. By 1889 it had spread over 359 square miles and was causing so much damage that the State of Massachusetts made an appropriation to eradicate it. This eradication campaign was prosecuted for ten years and was so nearly successful that the pest was considered to be of no importance and in 1900 the appropriations were discontinued. By 1905 the gypsy moth had spread over 2,224 square miles and was causing so much damage that both state and federal governments joined in suppressing it. Eradication was no longer considered. Millions of dollars have since been spent in preventing spread and in its control (9).

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*Porthetria dispar (L); family Lymantriidae

The gypsy moth larvae have been found to feed upon the foliage of 458 species of plants in confinement. Only 42 of these species, however, are satisfactory hosts. These favored hosts include oaks, willows, and birches.

There are certain other species like some conifers upon which the larvae, after the beginning of the third instar can develop, provided they have fed upon one of the favored hosts during the first two instars. For this reason the gypsy moth may be very destructive to white pine if this species is mixed in stands of the moths' favored hosts or adjacent to them (10).

Life History and Seasonal History

The gypsy moth has only one generation a year. Winter is passed in the egg stage. The eggs hatch in spring and the larvae feed on the young foliage of their various hosts. The larvae feed at night or on dark days. They are voracious feeders and when full grown the caterpillars are nearly three inches long. By early summer they pupate in flimsy cocoons on the tree trunks or limbs. The moths appear in late July and deposit eggs in masses of 350 to 400. The eggs may be deposited on the trunks or limbs of trees or on stones or fences. The female moth does not fly. Under natural conditions the species depends upon the larvae for distribution. Distribution by crawling is naturally slow, but larvae of the first instar have been known to be carried as far as 20 miles by the wind. This is possible because the newly hatched larvae can be supported in air currents by threads of silk which they spin. The larvae may also be transported by the agency of man. Probably, however, the egg is the stage in which it is most frequently transported for long distances.

Control

Two measures of indirect control are in practice which should reduce the abundance of the gypsy moth in regions where it is established. One is the removal of favored hosts or reducing stands as rapidly as possible. This results in protection of the less favored and often most valuable stands of trees, like pine. In addition, insect enemies, both parasitic and predatory, of the gypsy moth from Europe and Asia have been introduced.

A number of methods of direct control have also been used. Spraying with arsenate of lead is depended upon to destroy the larvae in cities, along roadsides, on private estates, or under certain circumstances in woodlands. Spraying is usually too expensive a measure to apply in forests unless they are of special esthetic value or are in eradication zones. Arsenate of lead is the insecticide most commonly used. A dosage of five pounds to 100 gallons of water should kill larvae not more than half grown. Sometimes when larger larvae are present it is advisable to increase the dosage. The addition of four fluid ounces of fish oil or linseed oil to each pound of the insecticide improves its adhesiveness and prolongs its period of effectiveness. The spray application should be made as soon as all of the foliage to be protected has expanded. If the application is delayed too long, the larvae become proportionately harder to kill (9).

Since the larvae prefer to feed at night and tend to hide on bright, sunny days, they can be trapped under burlap bands placed around the trunks of trees. Destroying the larvae requires a large amount of hand labor.

Banding trees that are uninfested with sticky material prevents larvae from climbing the trunks. Since the female moth cannot fly it also prevents moths from ascending trees and depositing eggs in the branches.

Control in winter depends largely upon finding the egg masses and painting them with creosote. To make the painted masses conspicuous, a small amount of lamp black or coal tar is added to the mixture.

Quarantine Regulations

To prevent the invasion of new territory by the gypsy moth, Quarantine 45 prohibits the free movement of: (1) coniferous trees...without roots, known as Christmas trees and parts thereof, and evergreen decorative plants...; (2) forest products including logs, tan bark, posts...; (3) trees, shrubs, vines, and all plants having woody stems and parts of such plants excepting seed and fruit; and (4) stone and quarry products". The first class, Christmas trees and evergreen boughs, were not allowed to move out of the generally infested area under any conditions. The other three classes of products may be moved subject to inspection and issuance of certificates (S. R. A.: 136).

In addition to prevention of spread by quarantine regulations, a barrier zone west of the area of continuous infestation and extending from Long Island to the Canadian border has been established. This barrier zone is from 25 to 30 miles wide. Within this zone it is attempted to prevent spread of infestation and to eradicate those infestations which occur. Spraying and creosoting egg masses is depended upon for control.

A number of times colonies of gypsy moths have been found at points quite distant from the generally infested area. The first was found at Geneva, New York, in 1912. Others have occurred at various locations in New York, New Jersey, Pennsylvania, and once as far west as at Cleveland, Ohio. Most of these were relatively small and were promptly eradicated cooperatively by federal and state regulatory forces. The largest of these outlying infested areas was found near Somerville, New Jersey, in 1920. At one time the infested area covered 924 square miles and the area covered by scouting and cleanup involved 2,369 square miles. Even from this large area the pest was eradicated. The last infestation in this area was located in 1929. Federal operations were discontinued in 1932. Since that time the state force has been continuing inspection in part of this area (9).

There is a large infested area in northeastern Pennsylvania which in 1938 covered 680 square miles in which eradication work is in progress.

SUMMARY

Many of our most destructive insect pests are not native to the United States. To prevent the introduction of others into this country and to prevent the spread of those recently introduced is the function of state and federal regulatory organizations. These organizations are also responsible for the eradication of newly established pests, if such work is to be undertaken.

Measures for eradicating the Mediterranean fruit fly from Florida were aimed first at the rapid succession of generations and the short life cycle of the pest. The removal of all host fruits for a period of time longer than the life cycle resulted in starvation. This measure was supplemented by spraying to destroy the adults directly.

The spread of the gypsy moth is subject to regulation because the females cannot fly. Natural distribution then, which depends on the larvae is necessarily slow. Regulation of commerce in products on which its eggs and larvae are likely to be moved for long distances is depended upon to prevent spread. Regulatory measures are supported by direct control which includes spraying of foliage to destroy larvae and killing the eggs by painting the masses with creosote during the dormant season.

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